ANL-7757

ANL-7757

THE EBR-II INSTRUMENTED-SUBASSEMBLY SYSTEM: TESTS 1 AND 2

A. Smaardyk, R. J. Dickman, J. R. Folkrod,
G. A. Forster, A. E. Knox, J. Poloncsik,
W. M. Thompson, and D. E. Walker

U of C-AUA-USAEC

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.95

ANL-7757
Reactor Technology

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

THE EBR-II INSTRUMENTED-SUBASSEMBLY SYSTEM: TESTS 1 AND 2

by

A. Smaardyk, R. J. Dickman, J. R. Folkrod,*
G. A. Forster,* A. E. Knox,* J. Poloncsik,
W. M. Thompson, and D. E. Walker

EBR-II Project

July 1971

*Engineering and Technology Division

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

THE EBR-II INSTRUMENTED-SUBASSEMBLY SYSTEM: TESTS 1 AND 2

by

A. Smaardyk, R. J. Dickman, J. R. Folkrod,
G. A. Forster, A. E. Knox, J. Poloncsik,
W. M. Thompson, and D. E. Walker

ABSTRACT

An instrumented-subassembly system for measuring operating parameters of specimen fuels, instruments, and related components in the core of EBR-II has been developed, fabricated, and operated successfully in the reactor. The fueled subassembly, which contained 23 instruments for measuring six different parameters, was irradiated for 140 days (3856 MWd) in the fifth row of the core, where it replaced a control rod. It was cooled by 700-900°F flowing sodium and exposed to a total flux of ~1.9×10^{15} n/cm^2-sec at a reactor power of 50 MWt. The complete system consists of the subassembly, which is similar to a standard EBR-II assembly; an extension tube with an internal coupling; a terminal box through which electrical leads and tubes from the sensors are connected to readout equipment; a drive system for raising and lowering the subassembly during fuel handling; and appropriate data-recording equipment. Before the irradiation of the fueled subassembly, the operational integrity of the system was verified by tests with a nonfueled subassembly while the reactor was subcritical.

I. INTRODUCTION

The EBR-II instrumented-subassembly system is an irradiation facility for direct monitoring of in-core experiments. As such, it augments a variety of noninstrumented irradiation subassemblies that have been used by experimenters in Experimental Breeder Reactor II (EBR-II) for a number of years.

EBR-II, operated under contract with the AEC by Argonne National Laboratory, was originally designed and operated to demonstrate the engineering and operational feasibility of the liquid-metal-cooled fast breeder reactor for application in a central-station power plant.[1] It successfully demonstrated its feasibility and that of the "quick-turnaround fuel cycle" it used. Later, the long-range national emphasis was shifted to large plants using ceramic fuels. This required EBR-II to provide irradiation facilities for a new and intensive test program for ceramic fuels and structural materials. Consequently, to enhance the test capability of the reactor, many irradiation subassemblies of various types were required. Many types of irradiation subassemblies have been designed and constructed that are different with respect to the number of fuel specimens, nature of exposure (encapsulated or unencapsulated), or special environmental conditions within the subassembly. None, however, has provided continuous and direct monitoring of test conditions.

Therefore, a study was made to determine the feasibility of installing a system capable of measuring operating parameters of specimen fuels and related components during irradiation in the EBR-II core. Emphasis was placed on: (1) maximum experimental flexibility, particularly with respect to the type and disposition of the instrument sensors within the subassembly; (2) compatibility of the system with existing reactor equipment and normal fuel-handling procedures; and (3) minimum reactor-shutdown time for installing and removing the system components.

Subsequently, research, design, and development led to fabrication of a prototypal instrumented-subassembly system, which was installed for performance evaluation in November 1969. The prototype, referred to as subassembly XX01, was removed from the reactor in April 1970, after five months of operation. This report deals with the design, installation, operation, and removal of the prototype, and presents test results obtained with it. It therefore is a source of information for planning and performing subsequent instrumented-subassembly tests in EBR-II.

The primary objective for the prototype was the development of a system, or vehicle, in which assemblies containing fuel or structural materials could be irradiated with instrument sensors and their leads. During the early studies, the decision was made to make two separate tests. The first test (Test 1) was installation of the hardware and dummy subassembly and a complete checkout of the system while the reactor was not operating. The second test (XX01), an extension of the first, but with fueled capsules in the subassembly, was an evaluation of the performance of the subassembly under 50-MWt reactor operating conditions. The objectives of this test were to assess (1) the full capability of the system during reactor operation and (2) the ability to continually monitor the fuel temperatures, coolant flow, pressures, and other parameters of the fuel, materials, and coolant within the subassembly.

II. DESCRIPTION OF SYSTEM

A. General

The instrumented-subassembly system[2] provides the means for inserting an instrumented subassembly into EBR-II (see Fig. 1) and for monitoring the various subassembly parameters while the reactor is operating. The system requires the extension of instrument leads from the reactor core region to an area outside the primary tank, where they can be connected to conventional data-logging equipment. The system has been designed to comply with all safety considerations and to be compatible with the present fuel-handling mechanisms. Because the reactor is compact, space requirements have been a major concern.

The instrumented-subassembly system consists basically of two major portions:

1. The "semipermanent portion," comprising the drive assembly and other components, which can be reused for subsequent irradiation subassemblies.

2. The "replaceable portion," comprising the instrumented subassembly and its extension. These components are replaced with each new experiment.

To make the system adaptable to future irradiation experiments, the replaceable portion provides a vehicle for capsules (supplied by experimenters) to be incorporated in a subassembly standard for every experiment. To demonstrate the capability and versatility of the overall system, a prototypal subassembly containing irradiation samples and instruments supplied by ANL was fabricated and tested in the reactor. The instrumentation was chosen to give a representative indication of the measurements that could be made in the reactor core. The system, however, is not limited to only the instruments of the prototype; it is fully intended to incorporate more-advanced measuring devices in future experiments.

The major components of the system are:

1. The subassembly (Fig. 2), which contains capsules with experimental irradiations (primarily fuel) and a variety of instrument sensors.

2. The subassembly extension, which comprises a 29-ft-long, concentric-tube assembly with a gripper at its bottom end and an electrical terminal box at the top (see Fig. 3). This tube is the connecting link between the subassembly and the system. A sodium-free drywell between the

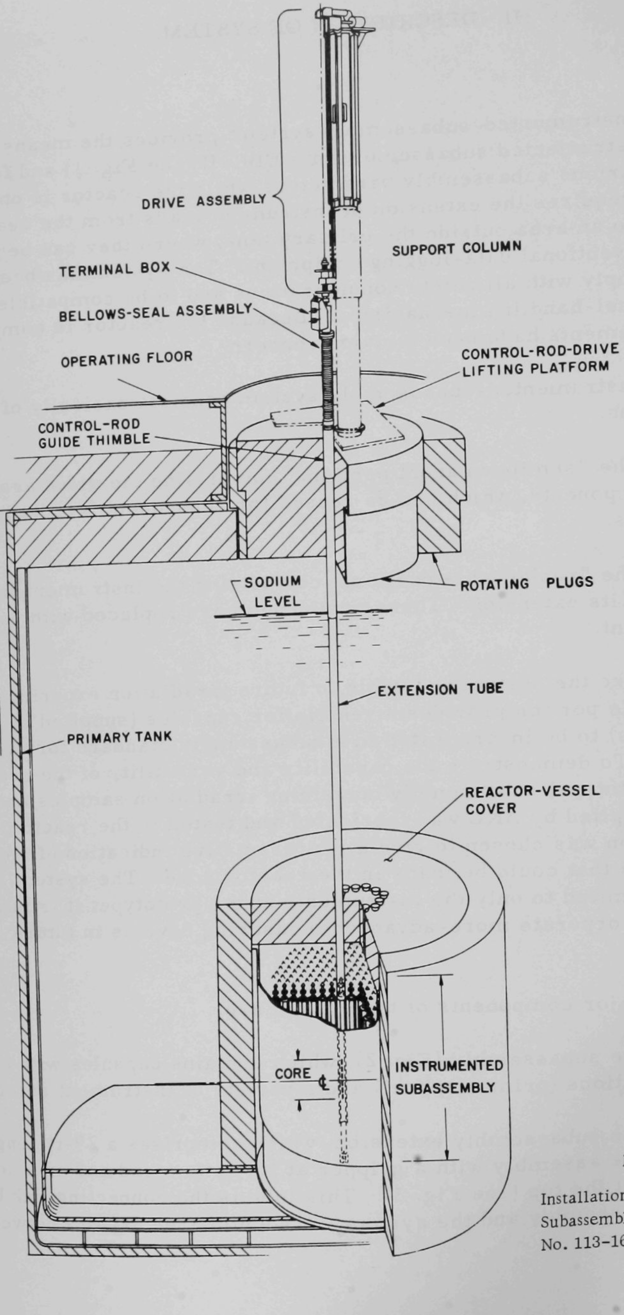


Fig. 1

Installation of Instrumented Subassembly. ANL Neg. No. 113-1608 Rev. 2.

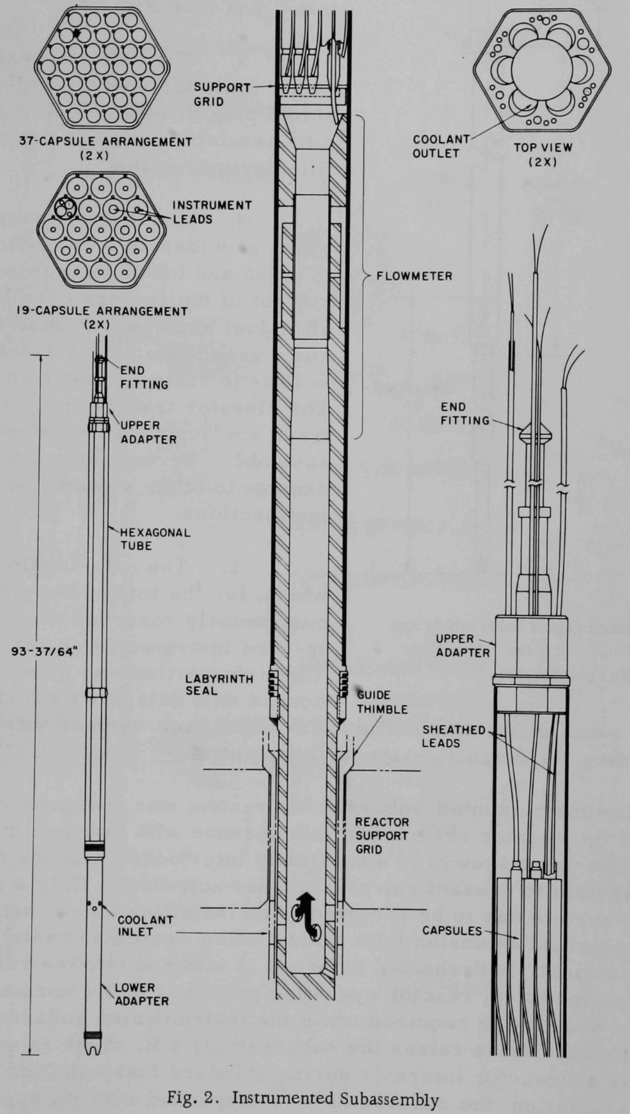


Fig. 2. Instrumented Subassembly

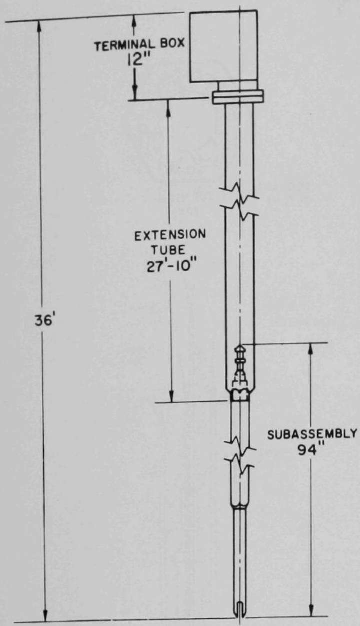


Fig. 3. Instrumented Subassembly and Extension Tube. ANL Neg. No. 104-142 Rev. 1.

inner and outer tubes is provided for routing the instrument leads to the terminal box (see Fig. 4).

3. The bellows-seal assembly, which seals the opening in the rotating shield plug through which the extension-tube assembly protrudes into the sodium-filled primary tank.

4. The drive assembly (Fig. 5), which provides an 8-ft vertical motion to raise and lower the subassembly in and out of the reactor core before and after fuel handling. It consists of a motor and a gear train, which rotate two lead screws to raise or lower an elevator arm. The elevator travels on a vertical guide track and supports the extension-tube assembly. Several safety devices prevent damage to other systems in case of malfunctions.

5. The data-logging system, which, for the test of the prototype (XX01), continuously recorded the output from the in-core instruments on analog strip charts. This information was also digitally recorded on a data-acquisition system outside the reactor building. The data-acquisition system was also capable of recording on magnetic tape at high speed.

The instrumented-subassembly system was designed to minimize change of the reactor system and interference with standard reactor operations. The drive system is electrically interlocked with the fuel-handling control system to prevent out-of-sequence activities. Only a small part of the drive system has to be removed when installing a new instrumented subassembly and extension tube. Installation causes no radiation hazard. The subassembly is preheated before it is lowered into the reactor. After it has been installed, reactor operation proceeds in the normal manner. When fuel handling is required while the instrumented subassembly is in the reactor, the drive raises the subassembly 8 ft, which is sufficient for it to clear all reactor internals during standard fuel-handling operations. During irradiation, the subassembly is suspended with its upper adapter 1 in. higher than the upper adapters of adjacent subassemblies.

By the time the instrumented subassembly is to be removed from the reactor after an irradiation experiment, it has had sufficient residence

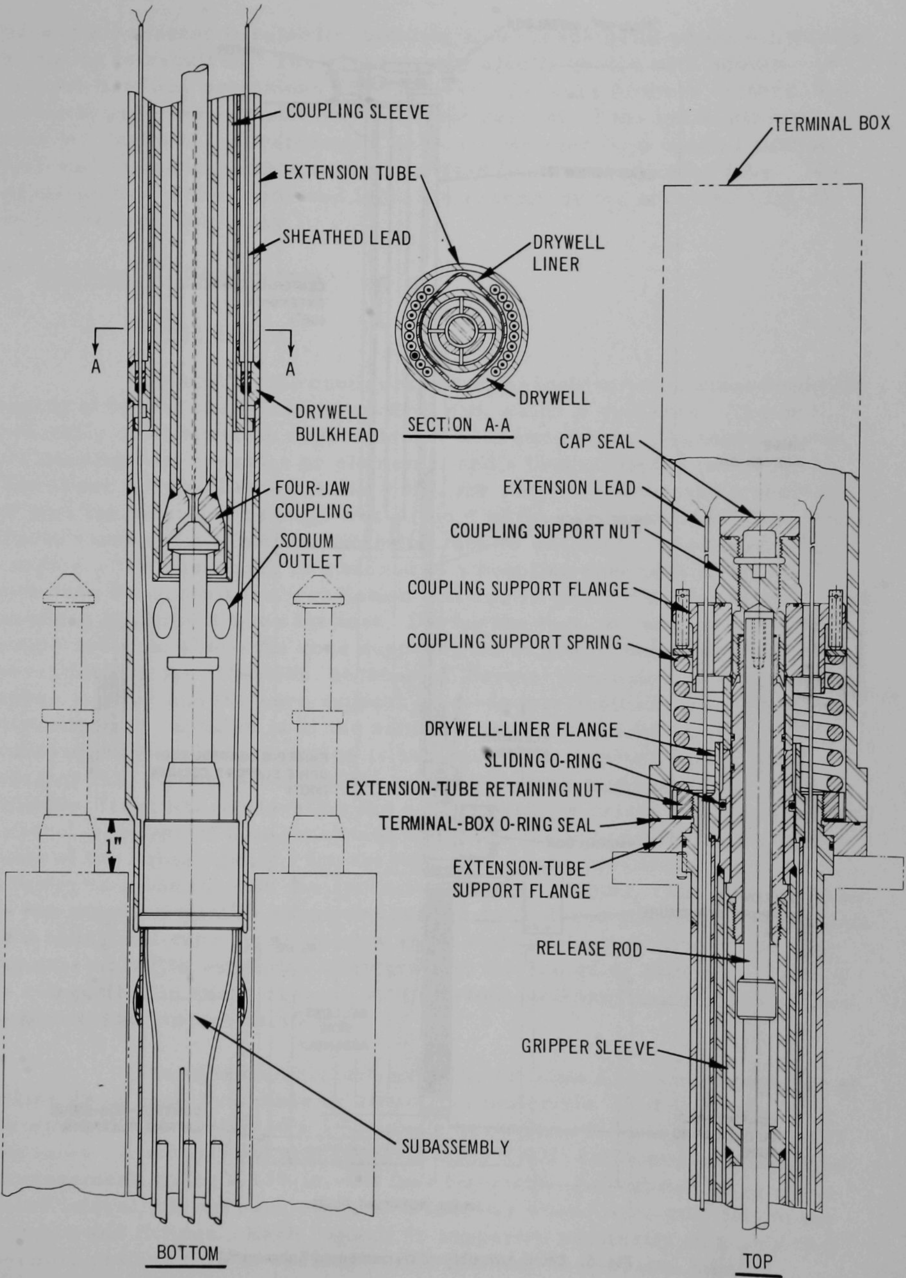


Fig. 4. Extension Tube of Instrumented Subassembly

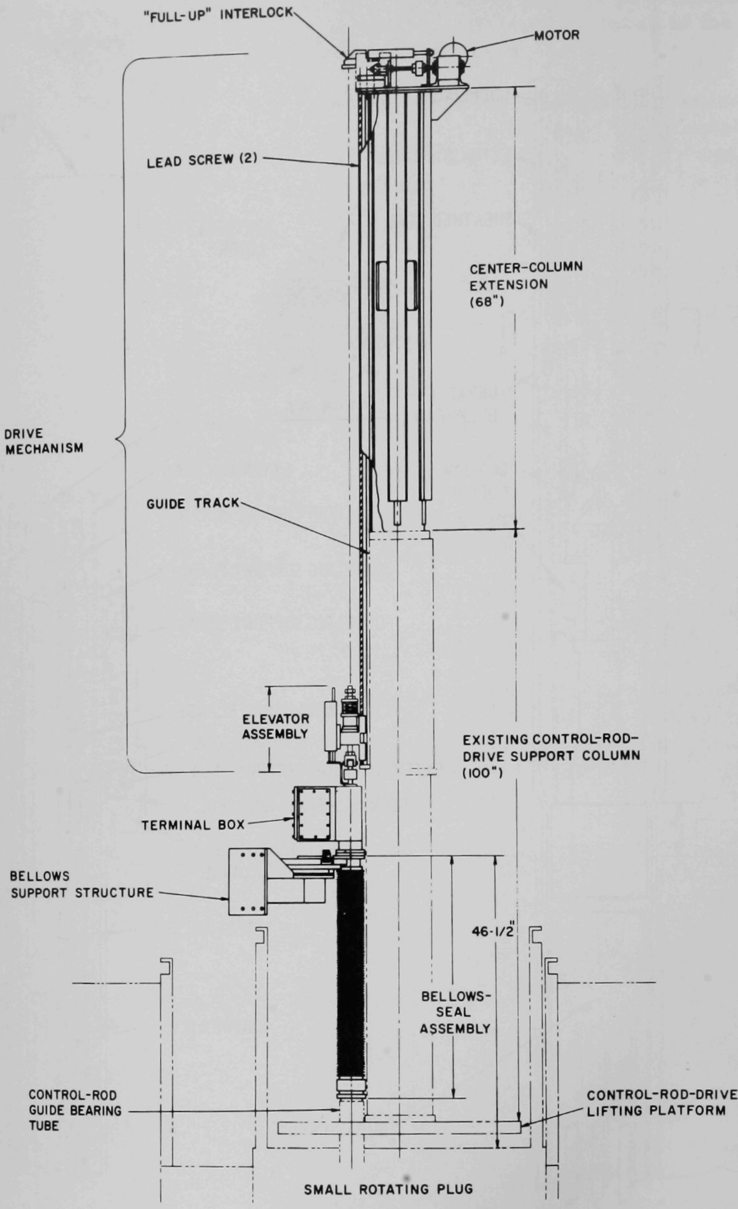


Fig. 5. Drive Assembly of Instrumented Subassembly

time in the reactor to raise its radiation level to the point where substantial shielding is required. The subassembly also is coated with sodium, so special handling provisions are required. Because of these factors, the removal procedure cannot be simply the reverse of the installation procedure. Instead, the instrument leads are severed by a special cutting tool, and the subassembly is disconnected from the extension tube. The subassembly is then removed from the reactor by the standard EBR-II fuel-handling equipment.

B. Mechanical Components

1. Subassembly

Outwardly, the configuration of the instrumented subassembly is identical to that of a standard control rod, which it replaces. The subassembly consists of an upper adapter with end fitting, a hexagonal tube for housing test capsules or elements, and a lower adapter (see Fig. 2). The upper adapter has six outlet holes for sodium coolant and a number of smaller holes for passage and support of the sheathed instrument leads. These leads extend into the extension tube to which the subassembly is coupled. The end fitting is attached to a coupling assembly in the extension tube throughout the irradiation test and is gripped by the existing fuel-handling equipment after the test. During the test, the subassembly is supported 1 in. above the core support grid to avoid compressing the subassembly and its extension, because of thermal expansion, between its upper support and the core support grid. In this position, the fuel in the experimental capsules is at the same elevation as the fuel in the other subassemblies. This elevation is achieved by a shoulder on the lower adapter that comes to rest on the existing mating shoulder of the guide thimble, from whose elevation the subassembly is raised 1 in. A standard control-rod type of hexagonal tube welded to the upper adapter forms the body of the subassembly. Except for some minor modifications, the lower adapter is identical with the control-rod lower adapter. The guide thimble is the standard thimble employed for all control-rod positions. It consists of a hexagonal-tube upper portion and a cylindrical bottom section. The subassembly fits within the standard control-rod guide thimble. Thus, it is compatible in every respect with existing fuel-handling equipment, procedures, and storage facilities.

The subassembly body can accommodate a number of capsules or elements of specimen fuels or structural materials. For example, subassembly XX01 contained a 19-capsule arrangement, using 0.357-in.-OD capsules. A subsequent test (subassembly XX02) contained a 37-capsule arrangement, using 0.230-in.-OD fuel elements. All capsules are separated laterally from each other by a spirally wound wire attached to the capsule and fittings. Each capsule is supported vertically on a grid that permits upward flow of sodium coolant through the capsule bundle.

Typical instrumentation includes fuel and coolant thermocouples, fission-gas pressure transducers, a flowmeter, and a flux monitor. One of the support-grid positions is occupied by a conduit for routing leads from inlet-coolant thermocouples and a flowmeter installed in the lower adapter.

2. Extension Tube and Terminal Box

The extension tube (see Fig. 3) provides a rigid connecting link between the instrumented subassembly and its drive system. The tube holds the subassembly in place throughout its irradiation period (including normal reactor-fueling operations) and absorbs the torsional reactions during the lead-severing operation. The instrument leads are routed through the extension tube to the terminal box above the rotating plugs of the reactor. The lower end of the tube fits over the subassembly upper adapter. During the irradiation, the extension tube passes through the reactor-vessel cover and a nozzle in the small rotating plug.

The extension tube (see Fig. 4) and the terminal box (see Fig. 5) make up the subassembly extension, which is firmly attached to the instrumented subassembly by a connecting assembly coupled to the end fitting of the upper adapter of the subassembly. The connecting assembly (from bottom to top) comprises:

a. A four-jaw coupling (see Fig. 6) for engaging the subassembly end fitting. The jaws are part of four 18-in.-long leaves attached to a tubular gripper sleeve, which is supported by a flange in the terminal box.

b. A coupling sleeve that retains the jaws in the engaged position.

c. A release rod for opening the four tapered jaws.

d. An extension-tube flange and a spring assembly (see Fig. 7) for supporting the subassembly. This assembly can compensate for a differential expansion of 9/16 in. between the coupling and extension tube.

A number of static O-ring seals maintain a gastight partition between the inside of the terminal box and the subassembly extension tube (see Fig. 4). In addition, one sliding O-ring is used between the gripper sleeve and the drywell-liner flange. This seal maintains tightness during the differential expansion between the coupling sleeve and the drywell liner that occurs when the subassembly is inserted into the primary tank.

The sliding O-ring seal was tested with the upper portion of the coupling sleeve and the drywell-liner flange; the differential expansion was simulated by manual displacement of the coupling sleeve that retains the sliding O-ring. Initially, helium leakage from the assembly was less than 3 x 10^{-9} cm^3 (STP)/sec. Then, with the seal subjected to a pressure differential of 16 psi for 648 hr while the sliding O-ring was displaced 200 times through a 0.5-in. stroke, no pressure loss was observed on a Bourdon-tube gauge attached to the system. This test showed that the sliding O-ring functions well under pressure.

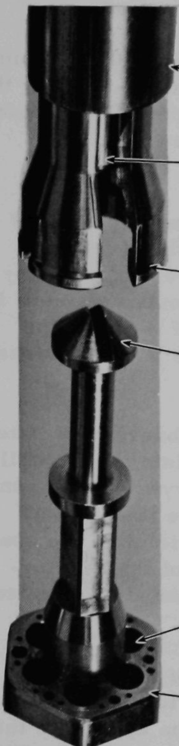


Fig. 6. Lower Portion of Connecting Assembly. ANL Neg. No. 112-9878B.

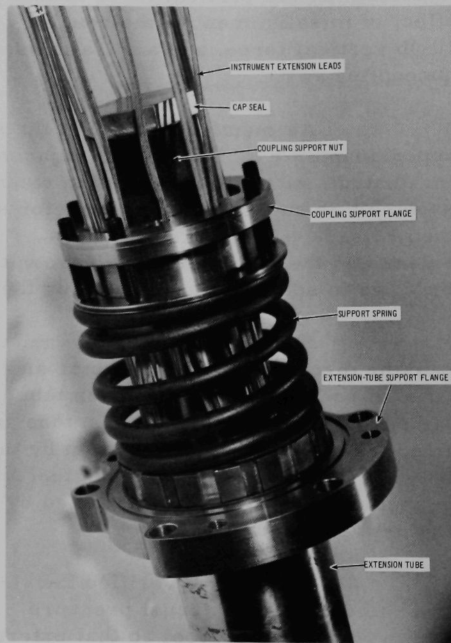


Fig. 7. Upper Portion of Connecting Assembly. ANL Neg. No. 113-2626A.

When the coupling is subjected to a vertical upward force, a taper on each jaw produces a force component outwardly in the radial direction. When the coupling sleeve is raised, this force component spreads the leaves apart. With the coupling sleeve in place, the outward deflection of the jaws is restricted, and the segmented leaves are in tension. The strength of the coupling has been substantiated by loading it to 3000 lb. Therefore, the coupling is as strong as standard core subassemblies.[3]

The instrumented subassembly is initially coupled to the extension tube during the assembling operations. It remains coupled throughout the irradiation period, which normally will include a number of fuel-handling operations for other fuel subassemblies, and is uncoupled only at the end of the period. After the uncoupling, the coupling sleeve and jaws are pulled up and removed from the extension tube. During this operation, the subassembly remains in the reactor, retained in place by the extension tube.

Coupling and uncoupling tests have been made in 700°F sodium to determine the vertical force needed to uncouple the jaws and to study the effect of misalignment of the coupling. Uncoupling was accomplished with a 10-lb vertical force, and a misalignment of 1/16 in. had no effect on uncoupling.

As mentioned earlier, the subassembly is suspended with its upper adapter 1 in. higher than adjacent subassemblies while it is being irradiated. After irradiation, the extension tube is lowered, and the subassembly is supported on the reactor support grid. The coupling sleeve is then raised $1\frac{1}{2}$ in. to free the jaws. Further withdrawal of the coupling sleeve and the inner tubular sleeve with attached jaws (see Fig. 4) causes the jaws to spread, thus uncoupling the subassembly.

Sheathed leads from various sensors in the subassembly, after passing through the upper adapter and a bulkhead, extend into the drywell (free of sodium) of the extension tube (see Fig. 8). The drywell is an annular space between the extension tube and an oval inner tube (the drywell liner) and is closed at the bottom by the bulkhead. For shielding, the space between the two tubes contains steel shot at the elevation of the reactor-vessel cover. The shot is retained by an intermediate bulkhead welded to the drywell liner.

Tests have verified the calculated capability of the drywell liner to withstand external pressure. A 6-ft length of the tube was sealed within a pressure vessel so that external pressure could be applied to the liner while the change in the internal minor diameter was measured. The liner exhibited completely elastic behavior to at least 80 psi; maximum deflection was 0.016 in. at this pressure. Because actual operating pressures in the instrumented subassembly are only 10-15 psi, testing beyond 80 psi was considered unnecessary. A limiting external pressure of 60 psi had been calculated for a tube with finite initial ellipticity. This pressure proved to be conservative, because the tests indicated that yielding does not occur at 80 psi.

Because of the limited space for making lead penetrations, brazing was chosen as the method of retaining and sealing the instrument leads in the drywell bulkhead. Brazing is done in one single operation in which all leads are positioned within the bulkhead and induction-brazed

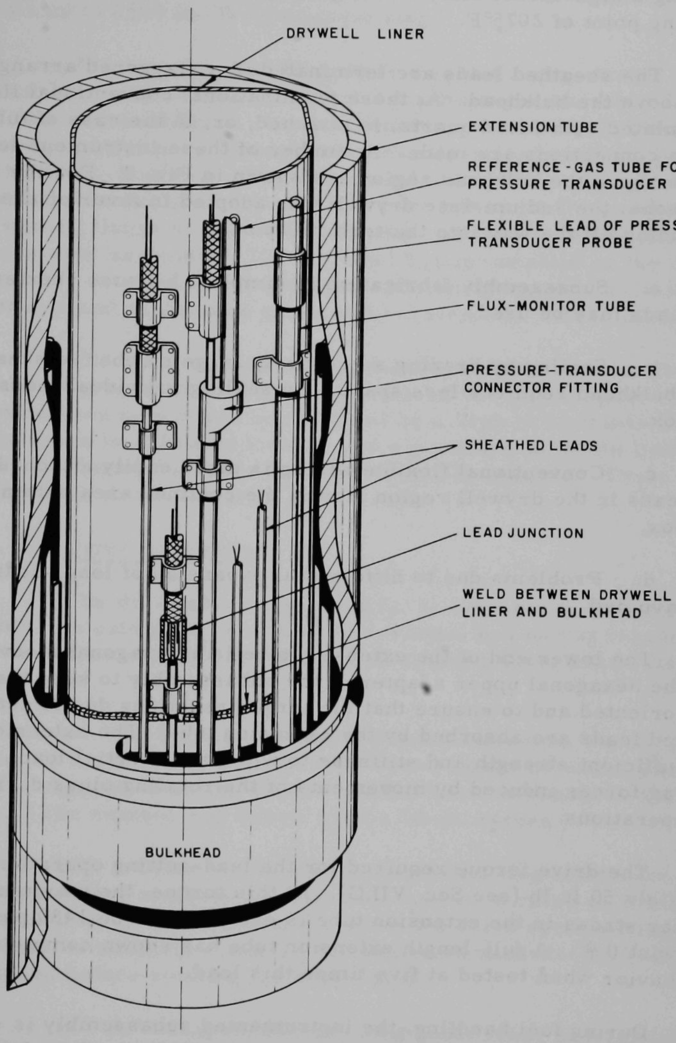


Fig. 8. Instrument Lead Wires and Tube Connections above Drywell Bulkhead of Instrumented Subassembly

simultaneously. A successful brazing technique (see Appendix C) has been applied using a high-nickel alloy brazing compound (Coast Metal 60), which has a melting point of 2075°F.

The sheathed leads are terminated in a staggered arrangement about 2 ft above the bulkhead. At these terminations, conventional flexible wiring, insulated with fused quartz, is attached, or, in the case of tubes, appropriate connections are made. A number of these instrument-lead connections above the bulkhead region are shown in Fig. 8. For the following reasons, the sodium-free drywell was adopted in favor of sheathed leads extending all the way into the terminal box:

a. Subassembly fabrication is simpler, because shorter sheathed leads may be used.

b. Sealing by brazing a relatively large number of sheathed leads in a bulkhead requires less space than sealing individual leads in the terminal box.

c. Conventional flexible wiring is more easily attached to sheathed leads in the drywell region than in the confined area within the terminal box.

d. Problems due to differential expansion of long sheathed leads are avoided.

The lower end of the extension tube is a hexagonal sleeve that fits over the hexagonal upper adapter of the subassembly to keep the subassembly oriented and to ensure that the torque reactions due to cutting of the sheathed leads are absorbed by the extension tube. The extension tube also has sufficient strength and stiffness to withstand inertial loads and sodium drag forces induced by movements of the rotating plugs during fuel-handling operations.

The drive torque required for the lead-cutting operation is approximately 50 ft-lb (see Sec. VII.G). At this torque, the maximum torsional shear stress in the extension tube is estimated to be 1480 psi, and the total twist 0.9°. A full-length extension tube has shown completely elastic behavior when tested at five times this load.

During fuel handling, the instrumented subassembly is subjected to a drag force as it moves with the rotating plugs. Calculations showed a negligible force of approximately 0.05 lb at maximum velocity when both the small and large rotating plugs are rotating in the same direction. An inertial drag on the subassembly is also possible because of the startup acceleration of the rotating plugs. The estimated upper limit for startup acceleration is 0.9 ft/sec^2. At this acceleration, the computed inertial drag is 8.4 lb, and the bending moment at the coupling is 90 in.-lb. This moment is acceptable, because the coupling has been subjected to moments up to 2500 in.-lb without yielding.

The terminal box (Fig. 9) is a sealed compartment in which the extension leads coming from the instrumented subassembly are connected to a terminal block. Connections from the terminal block to the readout equipment pass through hermetically sealed multipin connectors in the terminal-box wall. The box is sealed from the atmosphere as well as from the blanket gas of the reactor. Its bottom is flanged for sealing to the mating flange of the extension tube, and its top is bolted to the flange of the elevator assembly. The terminal box is installed on the instrumented-subassembly extension during the assembling operation. This allows the instruments and seals to be completely checked out before installation.

The terminal box and connecting drywell are charged with argon gas at 14 psig, a pressure higher than that of the blanket gas. Thus, a leak in the extension tube would be indicated by a drop in terminal-box pressure. This pressure is indicated locally, and a pressure-actuated limit switch initiates an alarm if a lower limit of 10 psig is reached. There is also a high-pressure alarm set at 15 psig.

3. Drive Assembly

The drive assembly (see Fig. 5) supports the instrumented subassembly, the extension tube, and the terminal box during irradiation and raises the subassembly 8 ft during fuel-handling operations. Its components are:

a. A 68-in.-long center-column extension, which is attached to the top of the existing control-rod-drive support column. This extra height is required to accommodate the 8-ft vertical travel of the subassembly. (The control-rod drives have a 14-in. stroke.)

b. A drive motor with a torque-limiting clutch and gear train, for rotating two ball-bearing lead screws to raise or lower the elevator assembly. An interlock attached to the drive system ensures locking of the elevator assembly (and the instrumented subassembly) in the "full-up" position before rotating the shield plug.

c. A V-shaped, 100-in.-long guide track and an elevator assembly for aligning the assembly of the subassembly and extension tube throughout its vertical travel. The track is bolted to the column extension. The elevator assembly, which is attached to the terminal box, has two independently operating load-sensing devices to detect binding of the subassembly during traversing.

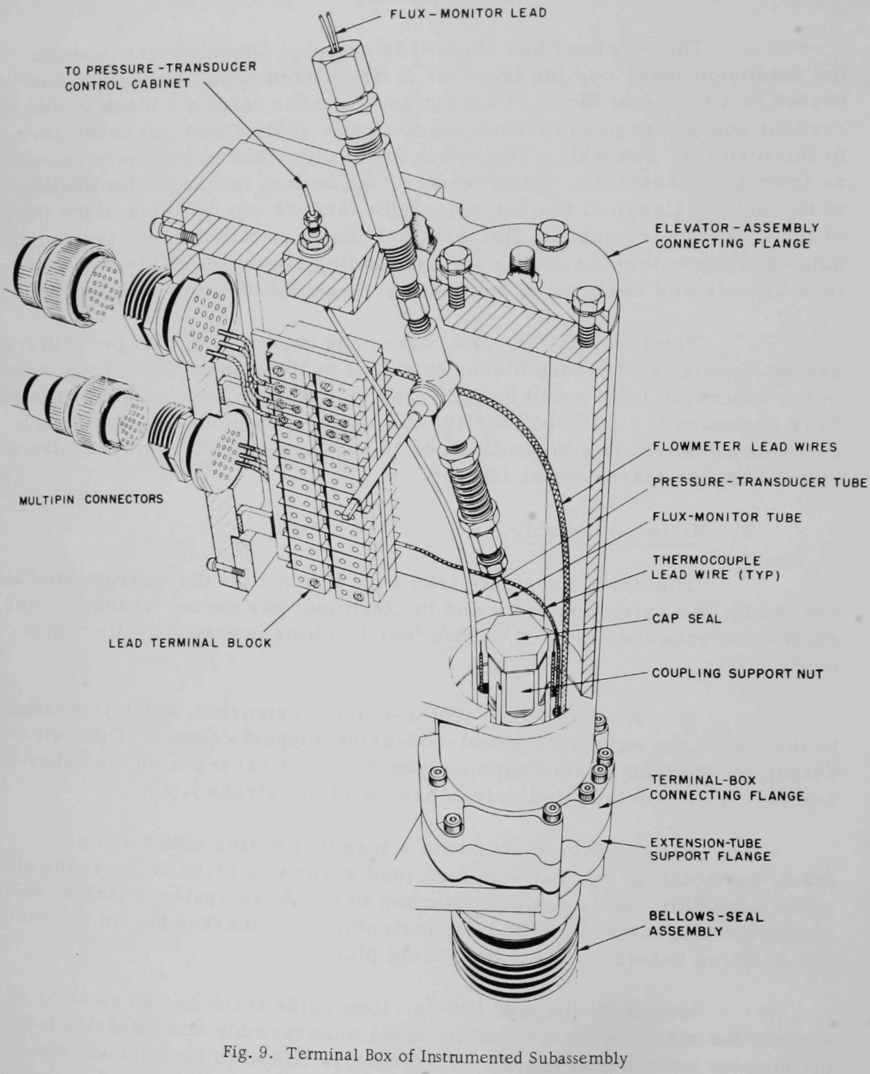


Fig. 9. Terminal Box of Instrumented Subassembly

The drive assembly provides a vertical stroke of 96 in., but has some overtravel (~3 in.) available for additional adjustment. It is operated by a three-phase ac, reversible gearmotor having an integral stopping brake (see Fig. 10). The motor speed is 1725 rpm, and the geared-down shaft has a speed of 11 rpm and a torque output of 140 in.-lb. A shaft torque of 65 in.-lb has been estimated for lifting the subassembly. The output shaft of the motor drives a mechanical torque limiter and a backstopping clutch that automatically locks the drive train when the drive motor is stopped. The output shaft of the clutch, through a 1:1 right-angle gear and a 1:2.92 gear set, drives the two lead screws at 32.2 rpm, a speed at which the linear travel rate of the elevator assembly is 16.1 in./min.

The ball-bearing lead screws and nuts for driving the elevator assembly are standard manufactured items. Each has a static load capacity of 3150 lb and an operating load capacity of 900 lb at 5000 cycles, and is thus capable of supporting the 400-lb estimated weight of the subassembly, its extension, and the bellows-seal assembly. The elevator assembly is moved vertically by the two ball-bearing screw-and-nut assemblies.

The elevator assembly (Fig. 11) supports the instrumented subassembly and its extension. It consists of an elevator arm, which is attached to the ball-bearing nuts on the lead screws, and a connecting link. The connecting link is composed of a spherical bearing, a connecting rod with spring support, and a force transducer with connecting flange. To prevent unequal wear, the screws must share the 400-lb operating load approximately equally. To accomplish this, the two screws are supported at the top ball bearing by three Belleville-spring washers. During assembling, dial indicators installed on top of the lead screws indicated variations in lead-screw elevation over the 8-ft vertical travel of the elevator assembly. These variations are attributed to slight accumulations in pitch error resulting from fabrication tolerances. With the elevator assembly supporting a 400-lb load at its lowest travel position, the dial indicators were set at zero. The elevator assembly was then raised by normal operation of the drive system. The maximum difference in lead-screw elevation, 0.0035 in., was observed when the elevator assembly was in the upper last foot of travel. With a spring constant of 8.8 lb/mil for the Belleville washers, this difference in elevation is estimated to be approximately equal to a 30-lb difference in load sharing between the two lead screws.

A sliding yoke, which is moved under the elevator assembly when the drive is up, is used as the "full-up" interlock. A limit switch is installed in such a way that it can be actuated only when the elevator is in the "up" position and the yoke engaged. This switch and the elevator "up" limit switch are interlocked with the rotating plugs and the fuel-handling console so that the plugs cannot be rotated unless the yoke is engaged and the appropriate position switches are actuated. The sliding yoke is engaged or retracted by an air cylinder, which is operated by a four-way, double-acting solenoid valve controlled by pushbuttons at the fuel-handling console. The

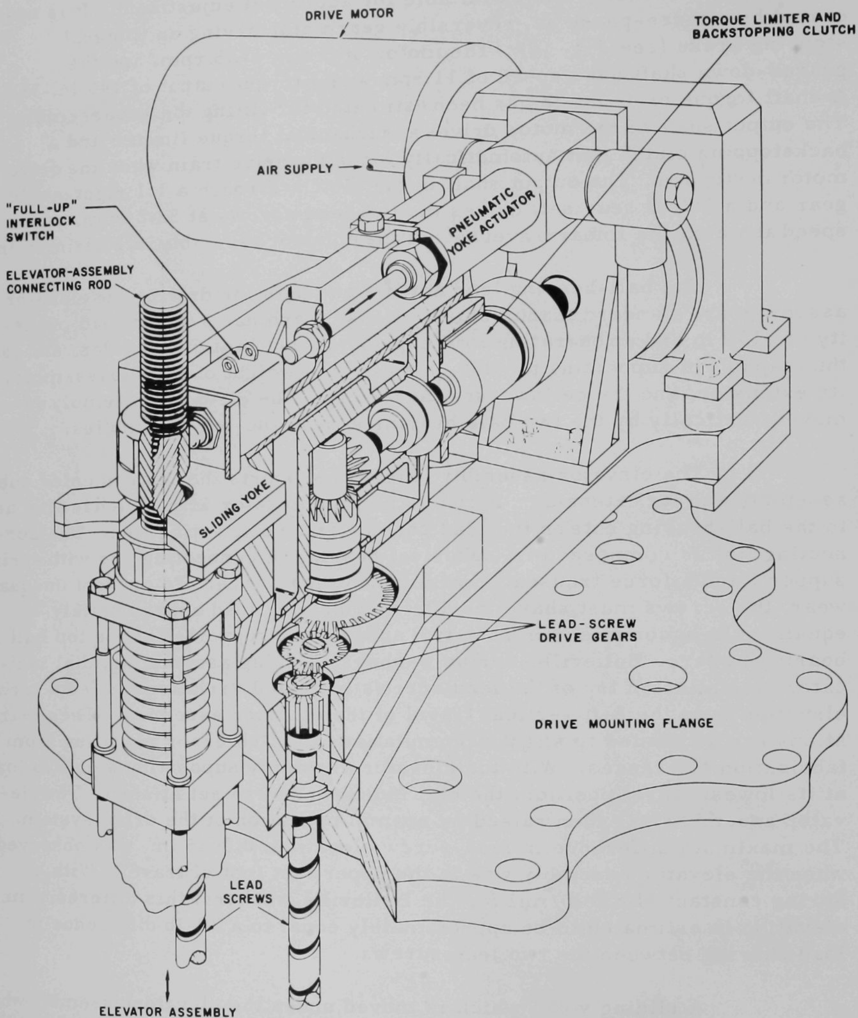


Fig. 10. Drive of Drive Assembly for Instrumented Subassembly

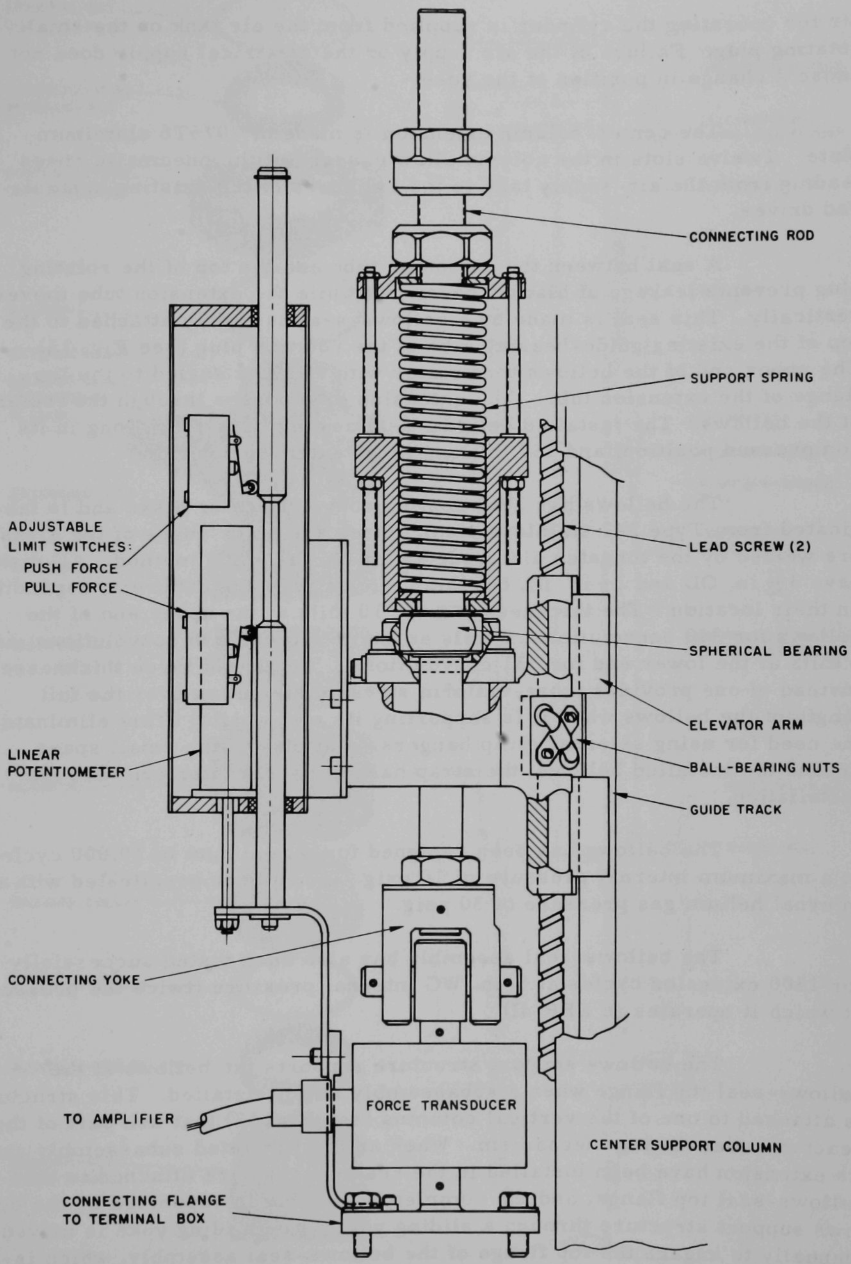


Fig. 11. Elevator Assembly of Instrumented Subassembly

air for operating the cylinder is supplied from the air tank on the small rotating plug. Failure of the air supply or the electrical supply does not cause a change in position of the yoke.

The center-column extension is made of 7075T6 aluminum plate. Twelve slots in the column allow passage of the pneumatic hoses leading from the air-supply tank to the cylinders of the existing control-rod drives.

A seal between the extension tube and the top of the rotating plug prevents leakage of blanket cover gas while the extension tube moves vertically. This seal is made by a bellows-seal assembly attached to the top of the existing guide-bearing tube of the rotating plug (see Fig. 12). The upper end of the bellows terminates with a flange sealed to the top flange of the extension tube. The extension tube passes through the center of the bellows. The installed bellows-seal assembly is 34 in. long in its compressed position, and 130 in. long in its extended position.

The bellows has 1069 nesting convolutions or disks and is fabricated from Type 347 stainless steel. Inner and outer edges of the disks are welded by the tungsten electrode and inert gas (TIG) method. All disks have $3\frac{23}{32}$ in. OD and $2\frac{5}{8}$ in. ID, but their thicknesses are different, depending on their location. The thicknesses are: 10 mils at the upper end of the bellows for 340 convolutions, 8 mils at the middle for 398 convolutions, and 6 mils at the lower end for 331 convolutions. The use of three thicknesses instead of one provides more-uniform stress distribution over the full length of the bellows when it is supporting its own weight. This eliminates the need for using external strap hangers. Because of the small space around the installed bellows, the strap hangers would interfere with the installation.

The bellows has been designed for a minimum of 10,000 cycles at a maximum internal pressure of 10 psig. It has been prooftested with an internal helium gas pressure of 30 psig.

The bellows-seal assembly has also been tested successfully for 1300 extension cycles at 5-in. WG internal pressure (twice the pressure at which it operates in EBR-II).

The bellows support structure supports the bellows at the bellows-seal top flange when a subassembly is not installed. This structure is attached to one of the vertical columns (see Fig. 13) that are part of the reactor-cover-lifting mechanism. When an instrumented subassembly and its extension have been installed in the reactor, they are attached to the bellows-seal top flange, and the complete assembly is supported by the bellows support structure through a sliding yoke. The sliding yoke is moved manually to engage the top flange of the bellows-seal assembly, which is

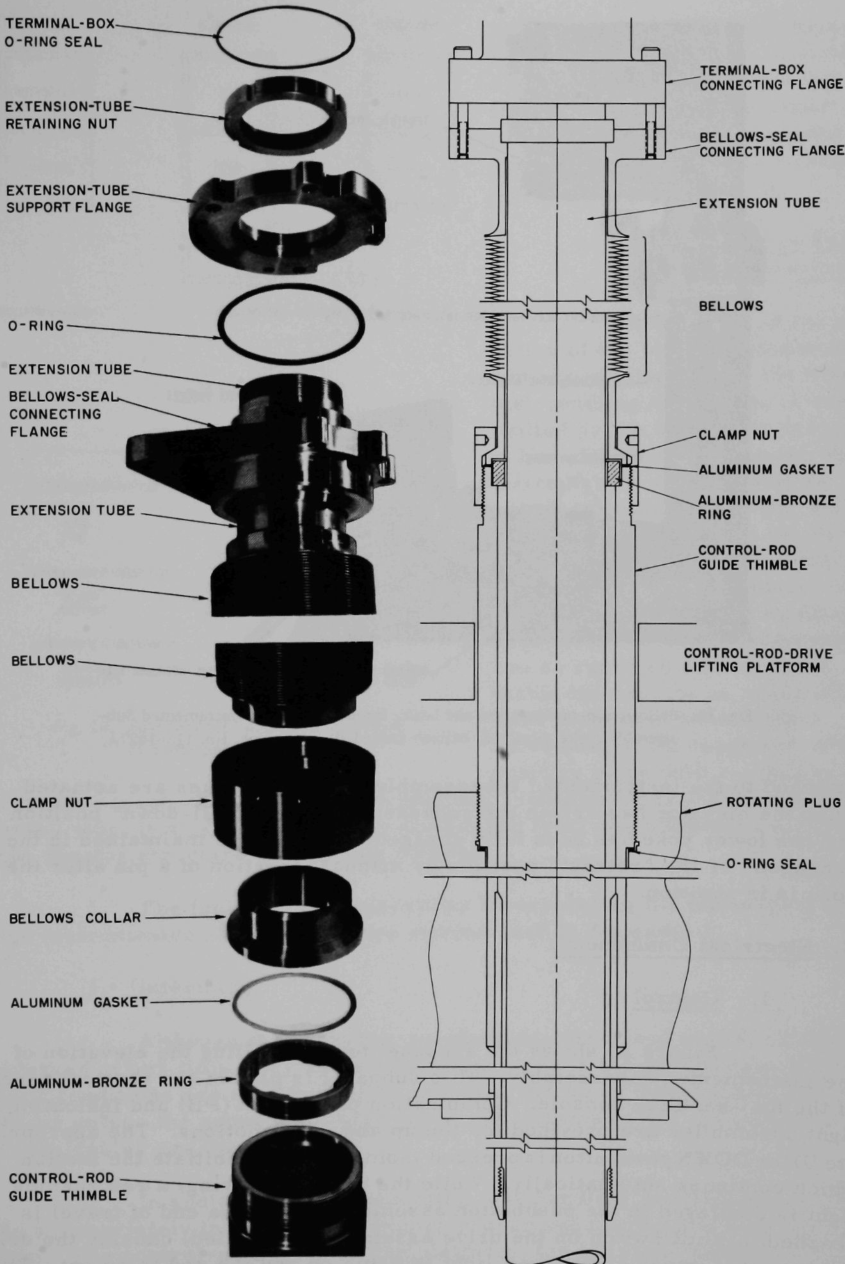


Fig. 12. Bellows-seal Assembly of Instrumented Subassembly. ANL Neg. No. 104-223 Rev. 1.

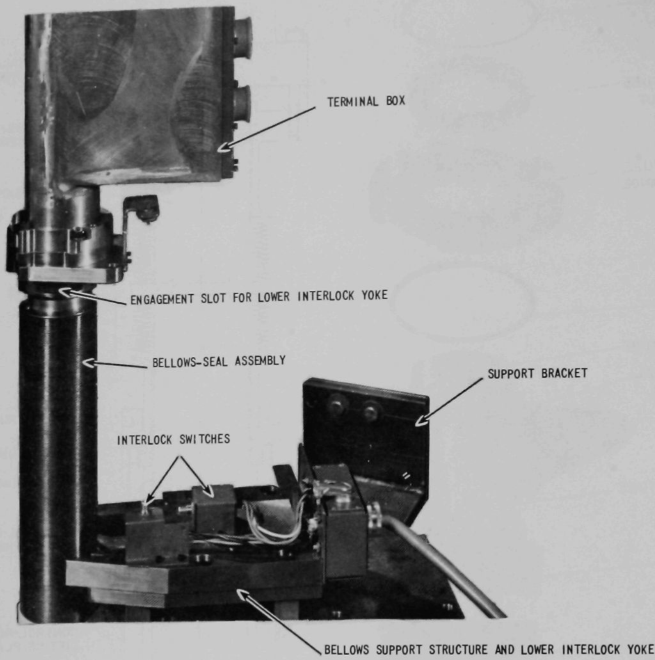


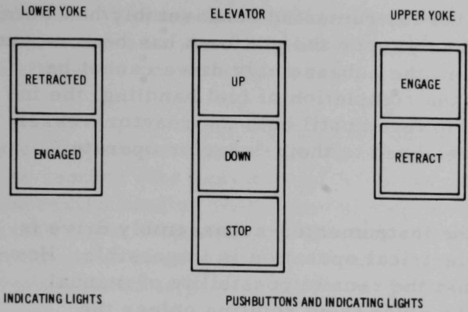
Fig. 13. Bellows Support Structure and Lower Interlock Yoke of Instrumented Subassembly (yoke retracted, bellows extended). ANL Neg. No. 113-1427A.

attached to the instrumented subassembly. Limit switches are actuated when the elevator has driven the subassembly to the "full-down" position and the lower yoke has been fully engaged. The yoke is maintained in the "engaged" or the "retract" position by manual insertion of a pin after the yoke is in position.

C. Electrical Components

1. Control

Figure 14 shows the subpanel for controlling the elevation of the instrumented subassembly. This subpanel is part of the vertical panel of the fuel-handling console. Combination pushbutton (PB) and indicating-light assemblies are provided for the up and down motions. The appropriate UP or DOWN pushbutton is pressed momentarily to initiate the motion which continues automatically. While the drive is moving, a red running light is displayed in the pushbutton assembly. When the end of travel is reached, a limit switch on the drive assembly is actuated, causing the drive to stop and a green completion light to come on and the red to go out. The



COLOR INDICATION

	OPERATION IN PROGRESS	OPERATION COMPLETED
ELEVATOR PUSHBUTTON		
UP	RED	GREEN
DOWN	RED	GREEN
STOP	WHITE	NONE
UPPER YOKE PUSHBUTTON		
ENGAGE	RED	GREEN
RETRACT	RED	GREEN
LOWER YOKE (LIGHTS ONLY)		
ENGAGED		GREEN
RETRACTED		GREEN

Fig. 14. Subpanel for Controlling Elevation of Instrumented Subassembly

STOP button provides for manual stopping of the motion. A similar arrangement of pushbutton control is provided for the upper yoke. Because the lower yoke is operated manually, only indicating lights are provided for it.

2. Relationship to Fuel-handling Sequences

Sequencing of the elevation of the instrumented subassembly with respect to the other fuel-handling operations is controlled by the interlocks described in Sec. 3 below. In general, the instrumented subassembly is raised to completely clear the other subassemblies in the reactor core before unrestricted fuel handling can take place. In the "unrestricted-fuel-handling" condition, reactor subassemblies can be removed and replaced within the reactor as required. This procedure necessitates movement of the large and small rotating plugs with respect to the reactor vessel. Because the instrumented subassembly is located on the small plug, it must be completely disengaged from any stationary parts of the reactor structure during plug rotation.

The fuel-handling operations incorporating the movements of the instrumented subassembly are summarized in Appendix J.

3. Interlocks

Although the operating pushbuttons, described above, can be pressed at any time, they are not functional unless the appropriate interlock conditions are satisfied. For example, the up or down motion cannot occur unless the upper and lower yokes are withdrawn and the instrumentation cables are disconnected.

In addition, other associated fuel-handling mechanisms must be appropriately interlocked to ensure proper sequencing and safe operation. The control-rod-drive lifting platform, for example, cannot be lowered to release the control rods unless the instrumented subassembly has been raised to its "up" position. Conversely, once the platform has been moved from its "reactor operate" elevation, the subassembly drive cannot be energized to move up or down. At the completion of fuel handling, the instrumented subassembly cannot be lowered until both the reactor-vessel cover and the platform have been returned to their "reactor operate" positions.

During fuel handling, the instrumented-subassembly drive is electrically disconnected so that electrical operation is impossible. However, as a further precaution against the remote possibility of manual movement, interlocking prevents the plugs from rotating unless the instrumented-subassembly drive is up and locked in its "up" position by the upper yoke. This condition is determined by a circuit connected through one of the cables (called "festoon cables") that remain connected during plug rotation.

After fuel handling has been completed, another interlock in the reactor-startup chain requires that the instrumented subassembly be both down and locked.

Table I summarizes all the interlocks, including those for force limits, which are described in Sec. 4 below.

TABLE I. Interlocks for Instrumented-subassembly System

	System Affected							
	Elevator Drive		Cover Drive		Platform Drive			
Necessary Interlock Condition	Up	Down	Up	Down	Up	Down	Plug Rotation	Reactor Startup
Unrestricted Fuel Handling Keyswitch KS-2 (administrative control)	x	x	x	x	x	x	x	
Elevator Up			x	x	x	x	x	
Upper Yoke Retracted	x	x	x	x	x	x		
Upper Yoke Engaged							x	
Terminal-box Blind Plate in Place	x	x						
Drive--Push Force within Set Limit		x	x		x			
Drive--Pull Force within Set Limit	x			x		x		
Rotating Plugs (and other fuel-handling mechanisms) at "Operate" Position	x	x						x
Elevator Down								x
Lower Yoke Engaged								x
Lower Yoke Retracted	x	x						

x = This interlock is required for the indicated operation to begin or continue.

4. Protective Devices

a. Limit Switches. Limit switches provide the signals for stopping the drive at discrete positions or in response to excessive forces. In all cases, however, the limit switches are backed up by mechanical stops, slip clutches, etc., so that ultimate safety does not depend on switch action. Where switch malfunction would cause considerable operating inconvenience or mechanical damage to a part, the final positioning of such switches is ensured by dowel pins, locking screws, etc.

b. Drive-mechanism Force Limits. Because there is relative motion between the instrumented subassembly and other elements inside the reactor (the reactor-vessel cover, adjacent subassemblies, etc.), any excessive binding with these elements must be detected. Any binding that could occur when the instrumented-subassembly drive is producing the motion, or when either the control-rod-drive lifting platform or reactor-vessel cover is producing the motion, is monitored in three ways:

(1) A prescribed deflection, in either direction, of the support spring that carries the weight of the subassembly and its extension tube deactuates one of two force-limit switches, one for push force, one for pull. The limit-switch circuits prevent further motion of the instrumented-subassembly drive motor in the direction that increases the deflection from normal. Reverse motion (to relieve the binding), however, is permitted. (These circuit functions also apply to the platform-drive and cover-drive motors.) The switches are normally actuated so that a loose or removed switch also causes the motor to stop.

(2) The spring deflection is also electrically monitored by a linear resistance potentiometer. The position of the wiper of the potentiometer is indicated by a meter, which has been adjusted so that the weight of the subassembly and extension tube is balanced out to read zero. The meter indicates forces in either direction and has adjustable limits connected in the motor-control circuits as above.

(3) The weight of the subassembly and extension tube is directly monitored by the force transducer independently of the measurement of spring deflection. A meter displays the combined load due to the subassembly, the bellows, and buoyancy. A set of high and low limits is provided at the meter.

Table II gives the settings for the force-detection devices for operating the drive. These settings take into account the contribution of the bellows, which varies from about 15 lb of compression when the subassembly is fully down to about 50 lb of pull when the subassembly is fully up. The buoyancy of the subassembly in sodium accounts for about 15 lb. The weight of the subassembly and extension tube is about 350 lb. Therefore, the force-transducer reading should be 320 lb when the subassembly is down and 400 lb when up. The potentiometer circuit is adjusted so that the meter readings are 0 and 80 lb, respectively, for the up and down positions.

TABLE II. Nominal Load Settings and Indications for Drive of Instrumented Subassembly

Condition	Settings or Indications, lb: Force Transducer and Indicator (including high and low lights)	Potentiometer and Indicator (including high and low lights and high and low trips)	Push-and-Pull Force-limit Switches (including high and low lights and high and low trips)
Subassembly in Down Position (first step for adjustments)	Force-transducer reading = Wt - Compr - Buoy; set low limit 25 less than this reading.	Adjust potentiometer to zero; set low limit to -50.	Adjust push-force limit switch to an equivalent of 100 (two lines on switch actuator rod).
Subassembly in Up Position (second step for adjustments)	Force-transducer reading = Wt + Ext; set high limit 25 higher than this reading.	Set high limit 50 higher than indicated reading (80).	Adjust pull-force limit switch to an equivalent of 100 (two lines on switch actuator rod).
Normal Range of Indication	320 to 400	0 to 80	
Limits of Drag Forces	25 to 105	50 to 130	100 to 180

Legend

Wt = Weight of subassembly plus extension = 350 lb.
Ext = Extension force of bellows = 50 lb.
Compr = Compression force of bellows = 15 lb.
Buoy = Buoyancy of subassembly (in down position only) = 15 lb.

c. Alarms and Indications. Separate alarm lights are provided for indicating excessive push or pull forces as detected by each of the three monitoring systems described in Sec. b above. A complete set is on the alarm-and-indicator panel, which is in an auxiliary five-bay cabinet adjacent to the fuel-handling console. Figure 15 shows the arrangement of this panel. The panel also contains the indicating meter (with its adjustable limits) and the zero and full-scale adjusting knobs for the linear-potentiometer force-monitoring system. The indicating lights for the pressure switches on the terminal box are also on this panel.

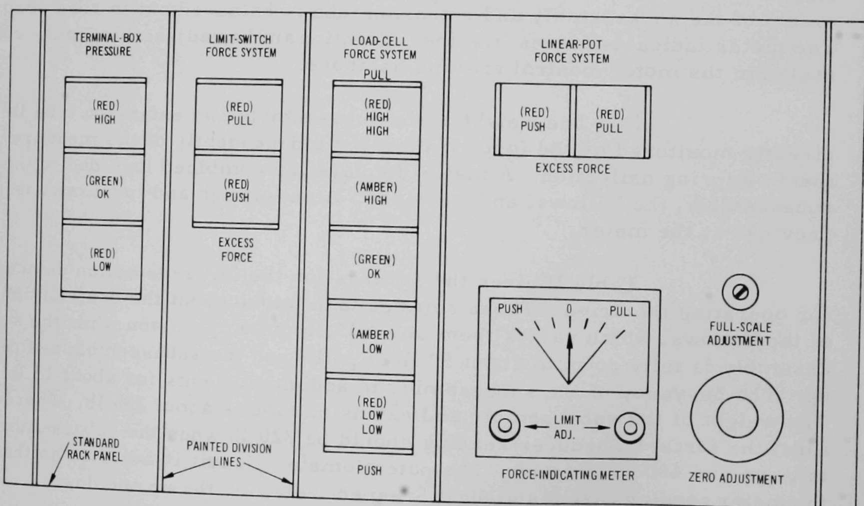


Fig. 15. Alarm-and-Indicator Panel for Instrumented Subassembly

The meter-amplifier unit associated with the force transducer (load cell) is on an overhead bracket on the small rotating plug, near the subassembly drive. It contains the meter that displays, on a scale of 0-500 lb, the load (subassembly, bellows, and buoyancy) on the elevator. It also displays the double sets of high- and low-limit alarm lights, which are duplicated at the alarm-and-indicator panel discussed above.

5. Control Components (Relays)

The internal control components, which are mainly relays, are in the auxiliary five-bay cabinet adjacent to the fuel-handling console. The relays are on a panel two bays wide, which is mounted on the right side of the back plate of the cabinet. Access is obtained through the two doors in front of the panel.

The relay panel contains 27 relays, eight 24-point terminal boards, a circuit breaker, three fuses, and the interconnecting wiring for these components. All connections outside the panel are made via wires and cables that terminate at the terminal boards. These wires and cables include a 37-conductor cable and a 12-conductor cable that connect to the main junction box at the drive mechanism; a 24-conductor cable to the alarm-and-indicator panel; a 19-conductor cable to the pushbutton control units on the vertical panel of the fuel-handling console; about 50 wires that connect to other circuits in the console, mostly for interlocks and power; and three wires for a terminal-box-pressure alarm in the reactor control room. Three wires in the small-plug festoon cable are used to maintain connections to the "full-up" and "upper yoke locked" limit switches for interlocking in the plug-rotation circuit, because the main cables are not connected during fuel-handling operations involving plug rotation.

Eighteen of the relays on the relay panel are Clark Controller Co. Type PMA. This is a heavy-duty relay that has been used extensively in the fuel-handling console and has given excellent service for the last 10 years. The contact ratings are 600 V ac, 10 A continuous, 60 A make, and 6 A break. The contacts are double-break and are housed in molded enclosures that separate each set of contacts so that a short circuit on one set will not damage the others. These relays are used for general-purpose interlocking and control.

The other nine relays are Potter and Brumfield Type KRP. This is a smaller, medium-duty, general-purpose relay. The contact ratings are 10 A at 120 V ac. These relays are used in a restricted manner. For example, the coils of seven of them, which require only 2 V-A, are energized by light-duty contacts in the two commercial force-indicating meters. The contacts of the relays, in turn, operate Clark relays whose contacts are used in the regular control circuits. The remaining two relays are energized by limit switches, but they operate only signal alarm lights.

6. Design Criteria

All control and interlocking circuits are designed to be consistent with the safety requirements and other general requirements for other EBR-II mechanisms. The following criteria have been used:

a. All circuits are fail-safe. For example, a control relay causes a positive action, like running a motor, only when energized; therefore, stopping the motor requires only interrupting the power to the relay. The only exception is the relays operating from the load-cell amplifier-indicator. Because of the internal contact arrangement of this commercial instrument, these relays energize in the limit condition. This exception was permitted because: the load-cell circuit is one of three force-sensing systems; it is the first of the three to trip; and the other two systems use the fail-safe criterion.

b. Wherever possible, limit switches with self-monitoring circuits are used to provide reliability. The wiring is arranged so the circuit path through the switch when it is actuated is opposite to that when it is deactuated, and each path passes through two, and in many cases four, contact points. Welding shut of any one of the contact points interrupts both circuits through the switch when the switch is actuated. One circuit interruption causes the action to stop (such as a motor stopping at its limit of travel), and another prevents the usual consequential completion signal from being produced, thereby calling attention to the malfunction before any damage occurs.

c. Wherever appropriate, as in the case of the force limits, limit switches are used in their actuated conditions, so that removal or a loose mounting results in an alarm condition.

d. Control circuits are protected with fast-flowing fuses to prevent welding of limit-switch and relay contacts in case of accidental short circuits.

e. In important cases, redundancy is used. For example, the interlock for plug rotation requires both the instrumented subassembly to be up and the "full-up" yoke interlock to be engaged, although the yoke engagement is sufficient by itself. Similarly, the interlock for reactor operation requires both the subassembly to be down and the "full-down" yoke interlock to be engaged.

III. GENERAL GUIDELINES FOR FABRICATING, ASSEMBLING, AND HANDLING THE SUBASSEMBLY

Individual components were fabricated either at ANL-Illinois or at commercial vendors with ANL-Illinois surveillance. The components were assembled into the complete subassembly and extension tube, with associated parts and instrumentation, at ANL-Illinois. All fabricating and assembling were done in accordance with strict quality-control requirements, which included control of material specifications as well as development and use of procedures for testing and inspecting materials, components, and completed assemblies.

These procedures, as well as the detailed procedures for inserting, operating, and removing the subassembly, were developed during the extensive R&D effort preceding insertion of the subassembly into the reactor. During this first R&D phase--the prereactor test phase--design features were verified. Testing included evaluation of coupling performance, lead-cutting operations in air and sodium, simulated flow tests, preparation and testing of mockups, and checkout of the full-scale subassembly system in ambient air.

In the second R&D phase, an instrumented subassembly containing only dummy capsules (no fuel) was installed in, operated in, and removed from the noncritical reactor. This in-reactor "rehearsal" test (called Test 1) was a checkout of the procedures that had been developed and of the integrity of the system and its components. Use of a dummy subassembly, which was not being irradiated, would have allowed rapid, simple withdrawal of the subassembly if the test had to be interrupted for review or correction. The test, which lasted several days, checked out:

a. Installation procedure.

b. Sequencing with respect to fuel handling and movement of the rotating plugs.

c. Operating performance at reactor coolant flows of 50 and 100% of full flow and at primary-sodium temperatures of 350-580°F.

d. Performance of coolant-flow and temperature instruments.

e. Instrumentation readouts.

f. Removal procedures, including retrieval and handling of gripper section, cutting of leads, and retrieval and handling of extension tube.

The drive assembly, which is the semipermanent part of the system, remained in the reactor after the rehearsal test. For Test 2, the prototype of the instrumented subassembly (XX01), containing fueled and instrumented capsules, was installed and coupled to the drive assembly.

This fueled subassembly was irradiated for more than four months. After the irradiation test, the prototype and its instrumentation were evaluated. The purpose of this test was to assess performance of the system for monitoring fuel and coolant parameters in the subassembly during reactor operation.

A. Quality Control

Quality control for Test 1 was concerned only with the dimensional and material requirements to ensure satisfactory installation and removal. Quality control for Test 2 was concerned with these requirements too, but also took into account heat transfer, materials-coolant compatibility, and nuclear and reactor safety to ensure integrity of the reactor and the experiment.

In addition to the established specifications provided by ASTM, ASME, AWS, etc., pertinent EBR-II product specifications for core components were used for design and fabrication. Also used were recently developed specifications for LMFBR in-core instrumentation.

Fabrication of the instrumented subassembly was essentially a toolroom and machine-shop operation. To provide clear and precise instructions for fabrication or procurement, the drawings served as primary instruments containing references to specific sections of applicable specifications. An overall inspection plan for ensuring that the requirements specified in the drawings and specifications were met was prepared by the manufacturing staff and reviewed by the cognizant engineer. All records were filed in a way that allowed retrieval of quality-assurance information relative to all fabricating steps.

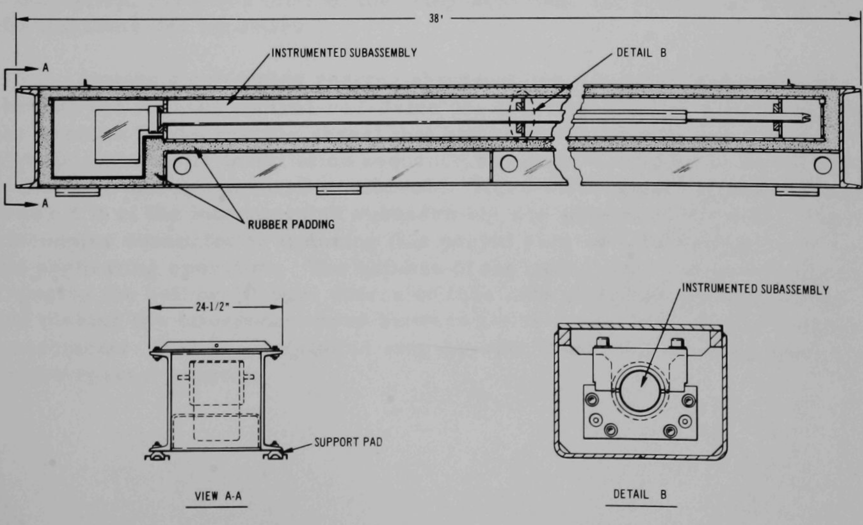
Assembling of the parts was coordinated using detailed procedures referenced on the corresponding assembly drawings. These procedures called for appropriate certification or sign-off by the cognizant engineer and/or by others. Deviations were recorded and were accepted only after management review.

The completed assembly of the subassembly and extension tube was given a complete measurement inspection to ascertain that it would fit into the reactor and could be handled with the reactor fuel-handling equipment. The as-measured dimensions were marked on a special control drawing and on an FCF Final Inspection Report, and both documents were filed for retention in the assembly record.

B. Handling and Shipping of Subassembly

During assembling, the combination of the instrumented subassembly and its extension tube was normally supported over its full length of ~36 ft in a horizontal position on long, specially constructed benches. Because of its slenderness, the subassembly would have been distorted if it were lifted at one point while horizontal. In the vertical position, however, the subassembly can be supported by simple means. To move the subassembly from horizontal to vertical, it was first strapped within a rigid, metal box support. Then, the box support and subassembly were upended together. When the box support was vertical, the subassembly was separated from it. The transfer from horizontal to vertical was done twice during the assembling operations: first, when the combination of the subassembly and its extension was to be placed into the brazing furnace for brazing the leads in the bulkhead; and second, when shielding shot was to be poured into the upper region of the drywell before the terminal box was attached. All other assembling operations were done while the subassembly and extension tube were horizontal on the assembling benches.

A special shipping container (Fig. 16) was designed for shipping Test 2 (XX01). It consisted of an inner and outer container. The subassembly was housed within the inner container and held in position by eight supports lined with rubber bushings. The inner container, much lighter than the outer container, also supported and protected the subassembly while it was being transferred into the reactor plant through the personnel airlock and while it was being upended. (The procedure for raising the inner container and freeing the subassembly from it is described in Appendix F.) The inner container was supported on all sides by the outer container through 2-in.-thick, sponge-rubber padding to prevent shock loads from being transmitted to the subassembly during transport. The outer container was made stiff enough to allow it to be supported at any point.



A structural analysis of the shipping container for Test 2 was made in accordance with Chapter 0529 of the U.S. Atomic Energy Commission Manual, "Safety Standards for Packaging of Radioactive and Fissile Materials." The analysis showed that the container conformed to the regulations set forth by the AEC and the Department of Transportation.

Test 2 (XX01) was shipped from the ANL Site in Illinois to the EBR-II Site in Idaho via an air-suspension household van. The shipment was made direct; no transfers were allowed en route.

IV. INSTALLATION AND CHECKOUT

A. Installing the Drive Assembly

Before the drive assembly of the instrumented-subassembly system was installed, the No. 6 control-rod drive, bellows, main shaft, and control rod itself were removed completely by normal procedures. The support column of the drive assembly was installed on top of the existing control-rod-drive support column. To accomplish this, the pneumatic-piston and shock-absorber assemblies of all control-rod drives were removed, and the pneumatic hoses normally connected to the air tank, which is integral with the support column, were rerouted. After the guide track, lead screws, and elevator assembly were installed, the complete drive assembly of the instrumented-subassembly system was aligned so that the centerline of the subassembly would align within 0.031 in. of the centerline of the control-rod opening during the entire length of travel of the subassembly. The support columns for the control-rod drive and for the drive assembly were then marked appropriately so all components of the drive assembly could be reassembled in the same position if they were disassembled later. The main components of the drive are installed semi-permanently; they need not be removed and reinstalled for subsequent routine installations of instrumented subassemblies.

B. Installing the Subassembly and Extension Tube

Before the assembly of the subassembly and its extension tube was installed in the primary tank of the reactor, it was thoroughly checked out at the reactor site. This checkout included visual inspection, dimensional verification, pressure tests of the integrated unit, and electrical tests of the instrumented circuitry.

During a scheduled reactor shutdown, the assembly was lowered through the vacated control-rod-drive position in the rotating plug and into the position in the reactor vessel that had been occupied by the control rod. This portion of the installation sequence was done according to established techniques and documented procedures. Before the insertion, however, the lower 8 ft of the instrumented subassembly was preheated for 8 hr. Thermocouples connected to it during this period recorded the heatup cycle in the preheating operation. The balance of the installation sequence involved engaging the bellows flange, extension tube, and electromechanical drive and making the interconnections between the terminal box and the readout instruments. Finally, a detailed step-by-step functional checkout was made before reactor startup.

C. Installing and Checking Out Electrical Controls and Interlocks

1. Installation

The system for electrical control and interlocking was installed in stages, as described below.

a. Wiring before Shipment. The elevator mechanism was completely wired at the Illinois Site. After each mechanical assembly of the mechanism was completed, its electrical components were wired. The wiring was arranged so that each mechanical assembly was a distinct electrical module. The wires were gathered into cables and terminated in multipin connectors. Junction boxes containing the mating receptacles were fabricated and located so the cables could be easily connected during final assembly. Three satellite junction boxes collect the cables from the dispersed parts of the mechanism. A fourth junction box (JB-4) collects all the cables from the satellite boxes and forms the main outgoing terminal for all wires on the mechanism. JB-4 has three output connectors; two contain the 48 connections to the control system that are disconnected before plug rotation, and the other contains the three connections that must be maintained for the interlocks during plug rotation. It also contains a complete set of terminal boards that make every wire accessible for checking.

To accommodate the 8 ft of vertical travel of the elevator, two seven-conductor retractile cords (Koiled Kords) are used for power, control, and high-level signals. These wires are connected to the load-sensing limit switches, the load-sensing potentiometer, the pressure-sensing switches on the terminal box, and the blind-plate interlock of the terminal box. Another cable, which carries the shielded low-level signal leads from the load-cell transducer to its amplifier, accommodates the vertical motion by running over a movable pulley supported by a constant-rate spring.

All wires and cables on the elevator mechanism were completely checked out during the mockup test in Illinois. The continuity of each wire was checked from the terminal points in JB-4 to each electrical component on the mechanism. All limit switches were operated manually to check circuit continuity. The wiring was also checked in an energized condition with a temporary test console (see Sec. b below). Because all wiring from JB-4 to the rest of the mechanism was the permanent wiring used in the final installation at the reactor, it did not have to be checked extensively later in the field. During disassembly for shipment, the electrical wiring was disconnected at keyed multipin connectors only, so exact reconnection was no problem.

b. Checkout with Temporary Test Console. A temporary test console, fabricated just before the mockup test in Illinois, contained all the control switches, control relays, lights, and indicators to operate the elevator mechanism in all its functions during the mockup tests and to indicate performance. It simulated the control and interlocking action of the final installations to the fullest extent practicable. The console was connected to the three output connectors of JB-4 and, therefore, to all the permanent wiring on the mechanism.

The console was also used during the final installation of the elevator mechanism at the reactor. It enabled direct control of the elevator during critical assembly procedures at the site, without use of the as-yet unchecked and heavily interlocked control system in the fuel-handling console.

c. Field Wiring. Part of the electrical installation in the field could be done early in the schedule without interfering with any fuel-handling or reactor operation. Several months before final mechanical installation of the instrumented subassembly, an auxiliary cabinet had been fabricated and assembled for anticipated modifications of the fuel-handling control system. The relay control panel for the elevator mechanism was fabricated, assembled, and partially wired for installation in this cabinet. There, the wiring was completed, and continuity checks were made. The alarm-and-indicator panel also was fabricated, wired, and installed in the cabinet. The control and indicating pushbuttons were installed and wired on the vertical panel of the fuel-handling console. All interconnecting cables were assembled and wired, and several were installed. All wiring, except that to be connected directly into the fuel-handling circuits, was completed and tested for continuity before the final mechanical installation was started.

During the final mechanical installation, the fuel-handling console was shut down, and the electrical installation was completed by putting in all wiring up to the three connectors that plug into the output receptacles of JB-4. However, as mentioned above, the three connectors from the test console were used with JB-4 first to aid in completing the mechanical installation. After the mechanical installation was completed and checked out with the test console, the connections were made to the auxiliary cabinet, thus completing the electrical system. The system was now ready for final checkout.

2. Final Testing and Checkout

The final testing and checkout program for the electrical system comprised: (a) cold testing (unenergized continuity testing) of the wiring of the elevator mechanism; (b) hot operational testing of the wiring of the mechanism, using the test console; (c) cold testing of the field wiring; and (d) hot operational testing of the complete system immediately after installation. The first three items have been briefly described in Sec. 1 above. The fourth, and most important, is described here.

The hot operational test, or complete checkout, was done in a formal manner using system checkout procedures previously prepared and reviewed as a basis for acceptance by Reactor Operations.

When the mechanical installation was completed, the final electrical connections were made to JB-4. A brief checkout ensued, in which errors were corrected and several adjustments were made. Then the formal checkout began. At each step in the operation sequence, every operational feature and interlock was checked. For example, the force-limit interlocks were checked by simulating the occurrence of an excessive force during the operation of the mechanism involved and noting that the mechanism stopped. The mechanism involved could be the instrumented subassembly itself or another component contacting part of the instrumented-subassembly mechanism, such as the reactor-vessel cover or the control-rod-drive lifting platform. Similarly, other interlocks that depend on relay contacts in the control circuits of mechanisms were checked out by physically pulling down the armature of the relay to open the contact and noting that the correct action ensued. Every step in the checkout was completed, and the corresponding steps on the check-off list for the checkout were initialed by a representative of Reactor Operations. The completed check-off list is now part of the quality-assurance record.

This one-time, exhaustive test need not be repeated unless significant changes are made in the system.

V. REMOVAL OF SUBASSEMBLY AND EXTENSION TUBE

A. Basic Sequence

After reactor shutdown, and preparatory to removal of the instrumented subassembly, the drive system and terminal box of the subassembly are disconnected from the extension tube, and the tube is separated from the subassembly. At this point, the extension tube is removed, through the rotating plug, into a pulling pipe for transport to a prescribed storage location in the reactor building.

The subassembly is removed from the reactor and transferred to the primary-tank storage rack by the existing fuel-handling mechanisms. After a 15-day decay period, the subassembly is removed from the tank (through a fuel-loading port) by the fuel-handling machine, deposited into the interbuilding coffin, and transported to the air cell of the Fuels and Examination Facility for disassembly.

B. Separation of Extension Tube

This portion of the removal sequence involves three major operations: (1) uncoupling the extension tube from the subassembly upper adapter, and removing the coupling assembly; (2) inserting the cutting assembly, and severing the instrument leads and tubes; and (3) removing the extension tube and the cutting assembly.

The coupling assembly is withdrawn from the extension tube and primary tank by using the pulling pipe and the procedures for removing control-rod drive shafts.

After the coupling assembly has been removed, the cutting assembly is lowered into the extension tube. The cutting assembly (Fig. 17) consists of: a 1.5-in.-OD, 0.25-in.-wall, ~29-ft-long hollow shaft; a retainer; a 0.5-in.-OD, ~28.5-ft-long internal, freely supported, sensing rod; and a cutter having two diametrally opposed, integral cutter blades. When the assembly is fully inserted, the shaft is supported by the upper adapter of the subassembly, the sensing rod contacts the conical end of the subassembly adapter, and the cutter is centrally positioned at the surface of the adapter (the cutting plane). The leads and tubes are cut by rotating the shaft (and blades) 180° with an electric motor. During rotation, the current in the motor armature is recorded to provide visual display of the cutting torque and sequence for each diametral pair of leads. After the leads have been cut, the subassembly is detached, but is restrained from movement by the extension tube.

Final separation is made by removing the extension tube and the cutting tool it contains. During the first 6 in. of upward travel of the tube

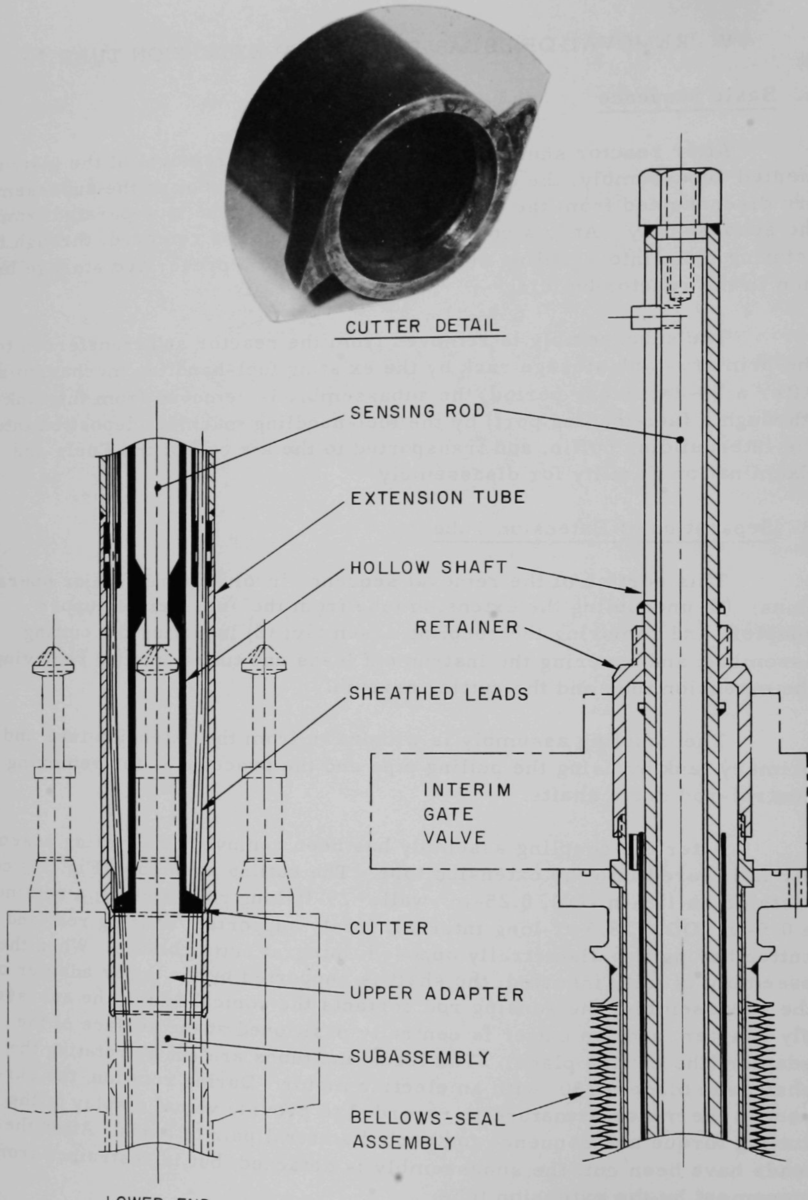


Fig. 17. Assembly for Cutting Leads of Instrumented Subassembly. ANL Neg. No. 113-2999 Rev. 1.

and tool, the sensing rod is held in contact with the subassembly so that the subassembly stays in place while the extension tube is being removed, thus ensuring that the separation of the extension tube from the subassembly is complete. Both the tube and the cutting tool are lifted partially through the rotating plug into the pulling pipe, allowed to drain and cool, and then completely withdrawn for transport to a storage location. A gate valve is installed to seal the vacated drive position until the subassembly is removed. If a fresh instrumented subassembly is not available for immediate installation in the reactor, a "dummy" assembly may be installed temporarily, as discussed in Sec. C below.

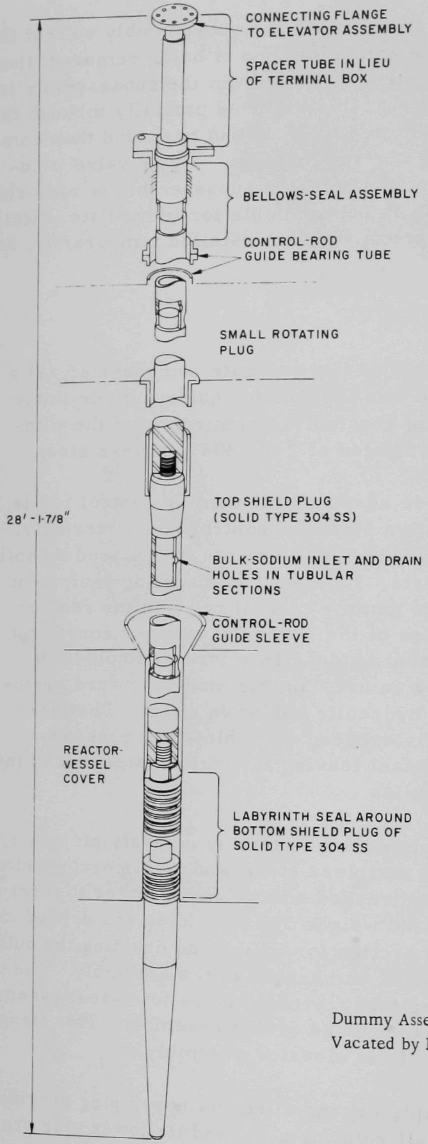
C. Dummy Assembly

The dummy assembly consists of two separate components: (1) a dummy control rod, which is loaded into the vacated guide thimble in the reactor vessel; and (2) a shield-plug assembly, which replaces the withdrawn extension tube. Both are fabricated of Type 304 stainless steel.

With one exception (the lower adapter), the dummy control rod is identical in external configuration to a standard control rod. Internally, however, the core section of 61 pin-type fuel elements is replaced by solid Type 304 stainless steel counterparts. Existing fuel-handling equipment and procedures are used to load the dummy control rod into the reactor. Design and hydraulic characteristics of the lower adapter are consistent with those of adapters on replacement Model IHE (increased holddown effect) control rods,[4] which are now in use. In this model, upward movement of the rod is restrained by a hydraulic holddown effect. The lower adapter of the dummy control rod is orificed with inlet-flow passages sized so the temperature of the coolant leaving it approximates that of the coolant leaving adjacent subassemblies.

As shown in Fig. 18, the shield-plug assembly consists of: a top and a bottom section made of solid stainless steel, and two interconnecting tubular sections. All sections are threaded and welded together to form an assembly that is 28 ft $1\frac{7}{8}$ in. long and weighs 300 lb. Holes are drilled in the top and bottom of each tubular section for filling and draining the bulk sodium coolant during installation and withdrawal of the assembly. The assembly is lowered, by the pulling tube, through the bellows-seal assembly, and is connected at the top to the flange of that assembly. This flange, in turn, is connected to the flange of the elevator assembly.

When the assembly is completely installed, its upper plug provides shielding in the opening of the small rotating plug, and its lower plug provides shielding in the guide sleeve of the reactor-vessel cover. A labyrinth seal around the lower plug restricts outleakage of primary sodium coolant through the sleeve. The end of the lower plug is 1/4 in. above the top of the dummy control rod, a clearance identical to that provided for the



holddown of adjacent subassemblies. The control rod, restrained from upward movement already by the hydraulic holddown effect of the Model IHE, cannot move upward farther than the lower plug.

Because the dummy extension tube is connected to the elevator assembly, any abnormal forces imposed on the tube or plugs while the reactor-vessel cover is being raised and lowered will activate appropriate safety interlocks in the drive-mechanism and fuel-handling circuitry.

D. Processing of Subassembly

The capsules are removed from the subassembly with the vertical assembler-dismantler in the air cell of the Fuels and Examination Facility. First, the lower adapter is severed with the hexagonal-tube cutter. Next, the upper adapter and leads are severed, and the hexagonal tubes are removed with the pullout drive. Finally, the capsules are separated and loaded into approved containers for shipment to other sites for postirradiation analyses.

Fig. 18

Dummy Assembly for Reactor Position Vacated by Instrumented Subassembly

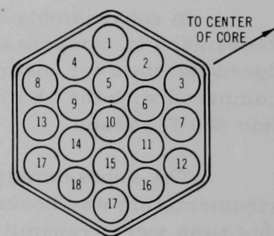
VI. TEST 1

Test 1 was a rehearsal operation in which an instrumented subassembly containing dummy capsules (no fuel) was assembled and installed in the reactor. After it had been exposed to flowing sodium, the subassembly was removed. The purpose of this operation was to verify design features and procedures to be used in assembling, handling, shipping, installing, and removing the fueled prototype of instrumented subassembly XX01, which was used for Test 2 (see Sec. VII).

Because the reactor was not operated during this rehearsal operation: (a) interruptions could be imposed at any time for review or corrections, (b) the subassembly could be withdrawn via the insertion route if required, and (c) complications that could be imposed by irradiated components were avoided.

The subassembly was constructed similarly to subassembly XX01. The capsule bundle contained 19 capsule positions. Eighteen positions were occupied by dummy capsules loaded with stainless steel rods instead of the fuel that would be in the subassembly XX01. One position was occupied by a tube serving as a conduit for the leads of a coolant flowmeter and an inlet-coolant thermocouple (see Fig. 19).

Instrument	Parameter Measured	Location	
		Capsule No.	Elevation
Thermocouples	Outlet-coolant temperature	5, 6, 14	Top of capsule bundle
Thermocouples	Inlet-coolant temperature	4	Bottom of capsule bundle
Thermocouples	Sodium-bond temperature	3, 10	10 in. above core centerline
			At core centerline
			9-1/2 in. below core centerline
Flowmeter	Flow through subassembly	4 (ext. lead only)	Below core



CAPSULE POSITIONS

Fig. 19. Instrumentation and Configuration of Test-1 Instrumented Subassembly

The subassembly was assembled at the Illinois Site and shipped to the Idaho Site in its special shipping container. On arrival in Idaho, it was checked out preparatory to the test.

Test 1 lasted several days. It was started by preheating the lower 8 ft of the subassembly in a special preheater to melt the capsule sodium bond from the top to the bottom. The ability of the preheater to melt the sodium bond in this manner was established in Illinois tests with a bundle of simulated subassembly fuel capsules. After the subassembly was removed from the preheater, it had to be transferred into the reactor before the sodium bond cooled and solidified.

The thermocouples measuring the temperature of the sodium bond in capsules 3 (edge of bundle) and 10 (center of bundle) were connected to readout equipment while the subassembly was being preheated, transferred, and inserted into the reactor. After 7 hr of preheating, the temperature of the sodium bond in capsule 3 had reached 580°F. At this point, the subassembly was transferred from the preheater to the reactor. About 14 min were required to transfer the subassembly and insert its lower end into the 350°F bulk sodium. The temperature of the sodium bond in capsule 3 dropped to 500°F in these 14 min.

The subassembly and extension tube were inserted gradually, in steps. They were initially held 124 in. short of the fully inserted position in the reactor bulk sodium. This was done to limit the differential expansion between the internal subassembly coupling and the extension tube to a value that would keep the displacement of the support-spring assembly within the design limit of 0.34 in. when the subassembly is lowered into 580°F sodium. The subassembly and extension tube were held at the 124-in. position for 6 hr to allow the coupling to heat and expand. After this 6-hr period, the subassembly was inserted to the 100-in. (short of full insertion), 64-in., and 28-in. positions and held for 4 hr at each position before being fully inserted. After the subassembly had been attached to its drive assembly, it was raised and lowered several times.

In subassembly XX01, the coupling was modified and the spring was redesigned to compensate for 0.80 in. of differential expansion. This reduced the time for inserting subassembly XX01 into the reactor to 5 hr, as compared with the 18 hr required for inserting the subassembly for Test 1 into 580°F sodium.

The subassembly was secured in the operating position, and all instrumentation was hooked up to readout equipment. The thermocouples by this time were transmitting temperature signals corresponding to the temperature of the reactor bulk sodium. The primary-sodium pumps were turned on, and a flowmeter signal was recorded. A flow rate of 27 gpm was recorded at 100% flow, and 12.5 gpm at 50% flow. These flow values are close to the anticipated values calculated for the uncalibrated flowmeter used for the test. All instrumentation remained functional throughout the test period.

To complete the test, the subassembly was uncoupled from the extension tube, the coupling was removed, the lead-cutting assembly was inserted, and the leads were cut. Then, the cutting assembly and the extension tube were removed (while the bulk sodium was at 580°F), and the subassembly was transferred from the reactor vessel to the fuel-unloading machine by normal fuel-handling procedures. Subsequent examination of the subassembly showed that the leads had been cut cleanly and flush with the surface of the top end fitting.

The satisfactory conclusion of the rehearsal operation:

1. Verified the adequacy of the design features required to incorporate the instrumentation and to facilitate installation and removal.

2. Confirmed the step-by-step procedures established for assembling, installing, and removing the subassembly.

3. Established the compatibility of the components of the instrumented subassembly with existing EBR-II fuel-handling and -unloading facilities.

VII. TEST 2 (SUBASSEMBLY XX01)

A. General

Subassembly XX01 was the first fueled subassembly in EBR-II to provide continuous sensor readouts during almost all phases of reactor operation.

To demonstrate the versatility of the instrumented-subassembly system, different types of instruments were incorporated in the Test-2 subassembly (XX01, also called the subassembly prototype). Table III shows the design criteria for this subassembly.

TABLE III. Reference Criteria for Instrumented Subassembly XX01

Subassembly	
Location (control-rod position)	No. 6
Configuration	Hex tube
Material	Type 304 SS
Dimensions, in.	
Across flats	1.902/1.912
Inside flats	1.824/1.830
Overall length	
Less lead length	$93\frac{37}{64}$
Inc. $28\frac{1}{2}$-in. lead	$122\frac{5}{64}$
Power output, kW	160
Coolant temperature at inlet, °F	700
Flow rate through subassembly, gpm	32
Coolant-temperature rise, °F	120-130
Vertical travel for fuel handling, in.	96
Speed of travel for fuel handling, in./min	16.1
Number of instruments	23
Capsules	
Number/subassembly	18
Material	Type 304 SS
Dimensions, in.	
Diameter	0.357 ± 0.001
Wall thickness	0.020 ± 0.0005
Length	$40\frac{13}{16}$
Spacer-wire diameter, in.	0.041 ± 0.0005
Elements	
Cladding material	Type 304 SS
Cladding dimensions, in.	
Diameter	0.290 ± 0.001
Wall thickness	0.020 ± 0.0005
Length	27.68
Fuel	
Material	UO_2
^{235}U enrichment, %	44.5 ± 0.1
Method of fabrication	Pressed and sintered
Dimensions, in.	
Diameter	0.246-0.247
Length	14.181-14.273
Theoretical density, %	85.6-93.1
Extension tube	
Material	Type 304 SS
Diameter (nominal), in.	2.5
Wall thickness (nominal), in.	0.120
Overall length (nominal) of subassembly, extension tube, and terminal box, ft	36
Total weight, lb	350

The instruments for this test were divided into two major application categories: (1) instrumentation to measure conditions within the subassembly; (2) instrumentation to measure conditions within the test capsules. The instruments were selected on the basis of availability and anticipated needs for future instrumented-subassembly experiments.

The subassembly contained:

3 outlet-coolant thermocouples
1 inlet-coolant thermocouple
1 flowmeter
1 $\frac{3}{16}$-in.-dia tube with a flux monitor
7 fuel-centerline thermocouples
4 spacer-wire thermocouples
4 fission-gas-pressure transducers
2 structural-material-centerline thermocouples

The subassembly contained 19 capsule positions, one of which was occupied by a tube that served as a conduit for instrument leads. Sixteen capsules contained uranium oxide fuel elements, and two contained structural material. All capsules and the conduit tube were helically wound with spacer wire. Tags of xenon gas were put into 10 of the oxide elements to determine if the tag had a measurable effect on fuel-centerline temperature.

Figure 20 shows the location of the capsules and instrument sensors in the subassembly, and Table IV enumerates the instrument sensors. Figure 21 shows typical arrangements of sensors in the capsules. Figure 22 shows the top end of the capsule bundle for the subassembly. It illustrates the uncluttered arrangement of the capsule closures, the instrument leads, and the special adapters for supporting the spacer-wire and outlet-coolant thermocouples. Each fuel element contains a stack of cylindrical UO_2 fuel pellets with some helium, in Type 304 stainless steel element-tube and end fittings. Each element is sodium-bonded to a capsule tube made of Type 304 stainless steel. A Type 304 stainless steel spacer wire is wrapped spirally on a 6-in. pitch around all capsules except four. On these four capsules, the spiral wire is replaced by a spiral-wire thermocouple lead. This lead consists of a sheathed thermocouple which is butt-welded to a spacer wire at the thermocouple junction. The spiral-wire thermocouple lead is attached to the capsule so that the thermocouple junction, which reads the temperature of the sodium coolant directly adjacent to the capsule wall, is at the same elevation as the fuel-centerline thermocouples in the same capsules.

Appendix B gives details of fabrication of the capsules.

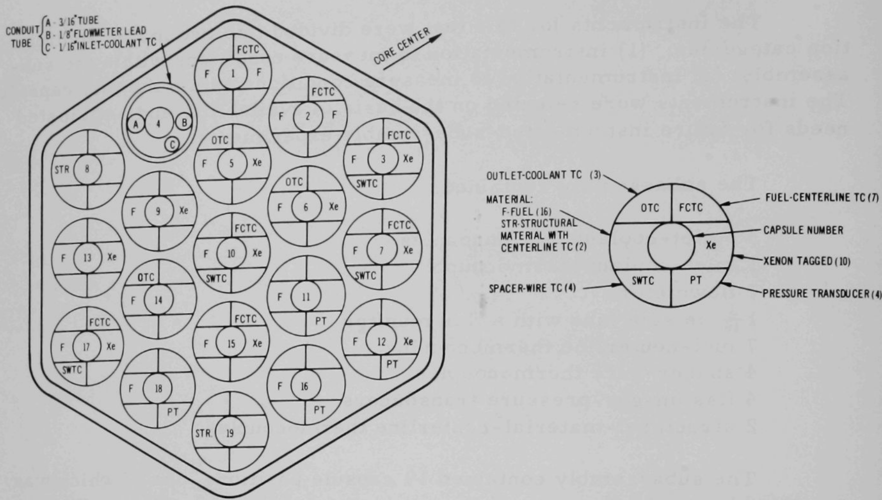


Fig. 20. Location of Capsules and Sensors in Subassembly XX01. ANL Neg. No. 104-145 Rev. 1.

TABLE IV. Instrument Sensors in Subassembly XX01

	Thermocouples						
Capsule Position	Centerline	Spacer Wire	Coolant Outlet	Coolant Inlet	Pressure Transducers	Flowmeter	Flux Monitor
1	X						
2	X						
3[a]	X	X[b]					
4[c]				X		X	X
5[a]			X				
6[a]			X[b]				
7[a]	X	X[b]					
8[d]	X						
9[a]							
10[a]	X	X[b]					
11					X		
12[a]					X		
13[a]							
14			X[b]				
15[a]	X						
16					X		
17[a]	X	X[b]					
18					X		
19[d]	X						

[a]Xenon tagged.
[b]Swaged construction: 0.040 to 0.062 in. in diameter. All others 0.062 in. in diameter.
[c]Conduit for leads.
[d]Structural capsule.

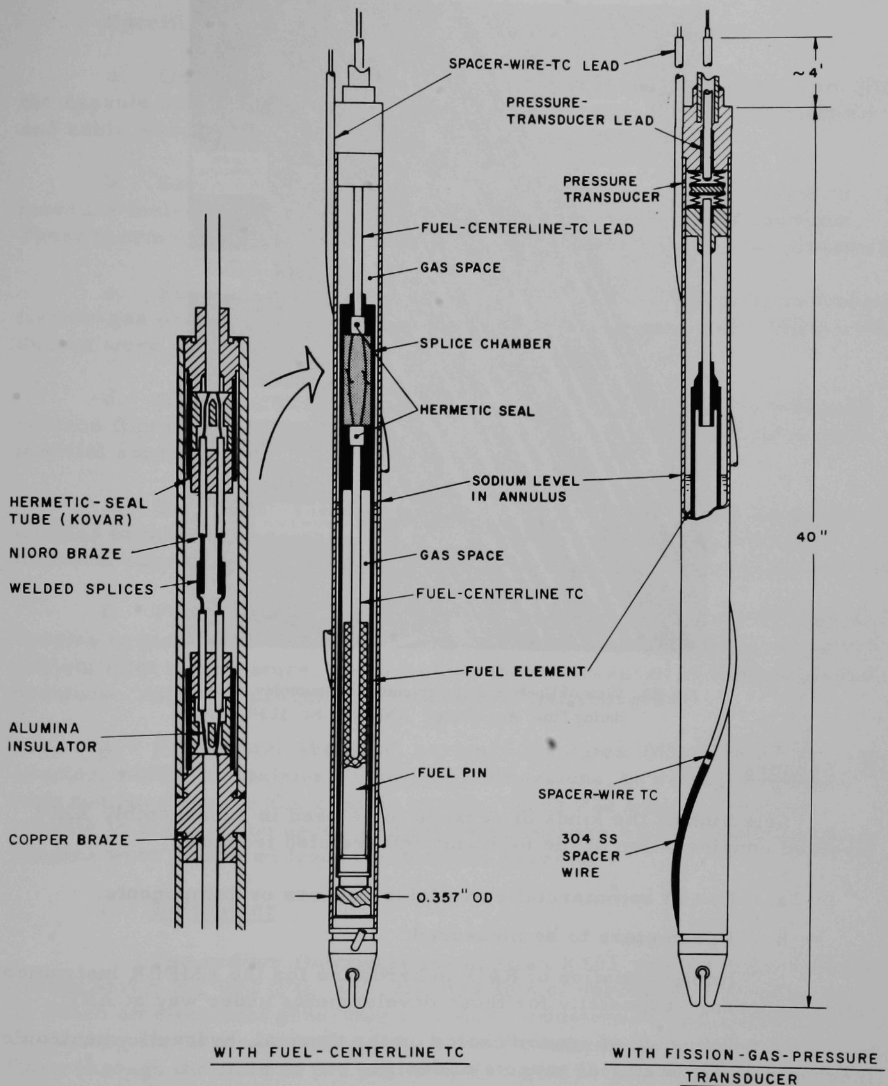


Fig. 21. Typical Instrumentation of Capsules for Subassembly XX01. ANL Neg. No. 104-146 Rev. 1.

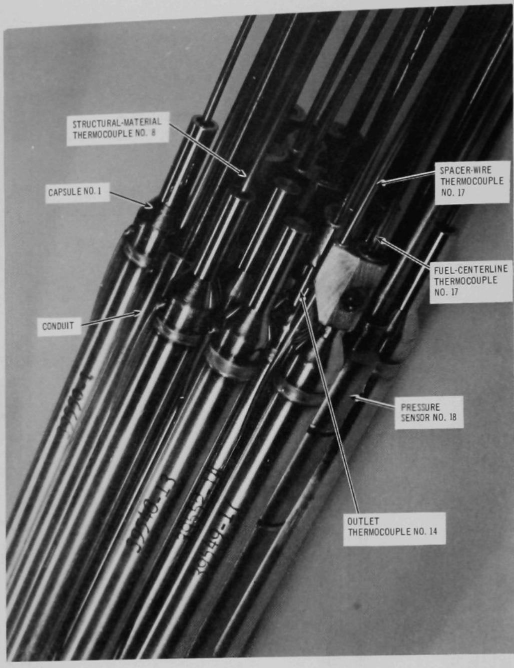


Fig. 22. View of Upper End of Capsules of Subassembly XX01 during Final Assembling. ANL Neg. No. 113-2510A.

B. Sensors

Selection of the kinds of sensors to be used in subassembly XX01 involved consideration of the following interrelated tradeoffs:

a. Use of commercially available sensors or components.

b. Parameters to be measured.

c. Implementation of R&D on hardware for the LMFBR instrumentation program--especially for those developments under way at ANL.

d. Influence of sensor choice on the thermal, hydraulic, neutronic, mechanical, and material aspects of design.

e. Amount and accuracy of useful information available from various kinds of sensors--especially information not previously obtainable at EBR-II.

f. Likelihood of success for various choices, especially for several months of irradiation.

g. Compatibility with EBR-II irradiation-experimentation requirements.

Specific choices that resulted from the tradeoffs were:

a. One permanent-magnet flowmeter to measure sodium flow into the capsule bundle. The flowmeter was assembled at ANL. The magnets and cable were commercially made to ANL specifications.

b. Seven metal-sheathed, ceramic-insulated thermocouples to measure fuel-centerline temperatures in each of seven fueled capsules. These thermocouples were assembled at ANL from commercial components.

c. Four pressure transducers, of the null-balance type, to measure fission-gas pressure within a plenum in each of four capsules. These transducers were procured from a commercial source.

d. One subminiature, self-powered neutron detector to measure neutron flux in the conduit tube. The detector was procured from a commercial source.

e. Two metal-sheathed, ceramic-insulated (ISA Type K) thermocouples to measure centerline temperatures in each of two structural-material capsules. Each of these was procured from a commercial source.

f. Four metal-sheathed, ceramic-insulated (ISA Type K) thermocouples to measure sodium-coolant temperatures. One of these measured sodium inlet temperature, and the other three measured sodium outlet temperature. All were procured from commercial sources.

g. Four metal-sheathed, ceramic-insulated (ISA Type K) thermocouples, welded to stainless steel-wire extensions, to measure spacer-wire temperatures in the capsule bundle. Each was wrapped around a capsule in place of the usual stainless steel spacer wire. These thermocouples were procured from commercial sources.

1. Flowmeter

The sodium flowmeter installed in XX01 was the EBR-II Mark-II design Serial No. 003 (Fig. 23). Its principle of operation is similar to that on which an electrical generator is based: induction of voltage across a conductor moving in a magnetic field. In the flowmeter, sodium (the conductor) flows through the field of two permanent magnets. The voltage is measured at two radially opposite points on the flow tube that are at right angles to the magnetic flux and to the flow direction. In this type of flowmeter, there are no moving parts and only stainless steel is exposed to the sodium. The output voltage is linear with flow (including reverse flow) and may be connected to a conventional millivolt recorder.

In the Mark-II design, two Alnico-5 magnets and two soft iron pole pieces surround a 5/8-in.-ID flow tube. The contacts are connected

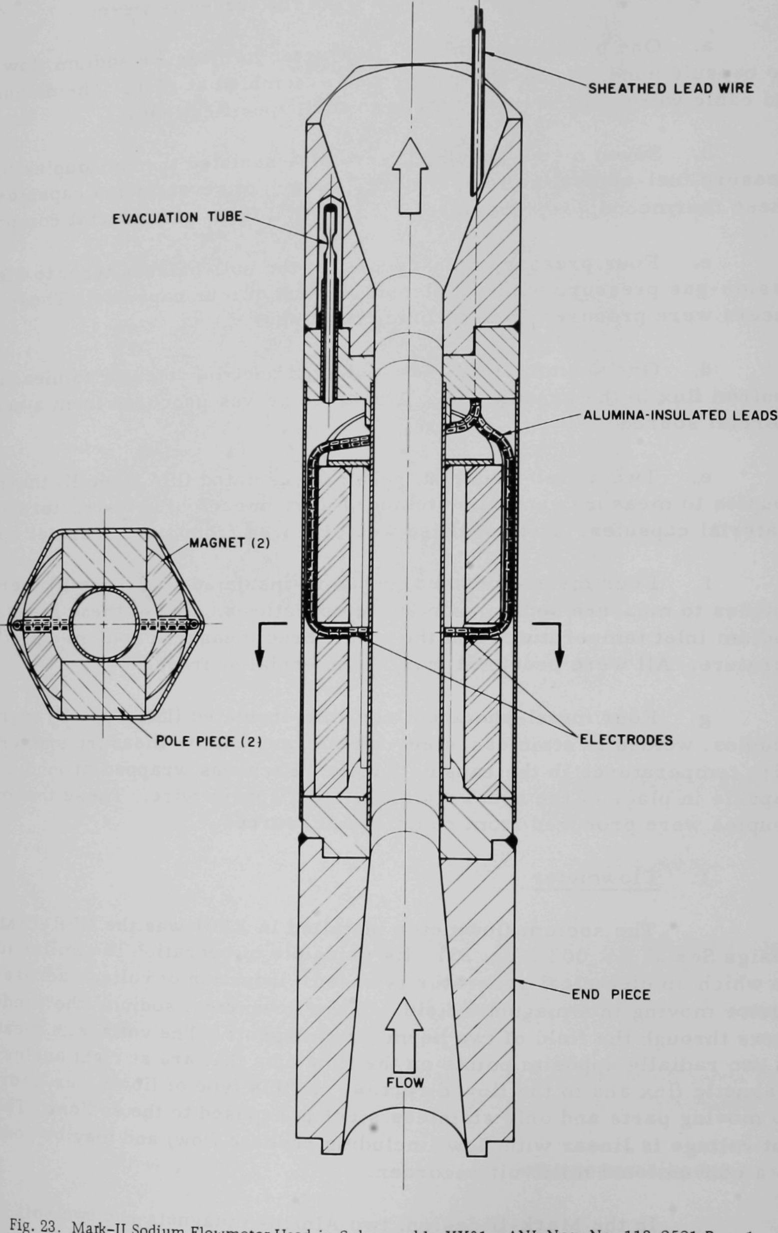


Fig. 23. Mark-II Sodium Flowmeter Used in Subassembly XX01. ANL Neg. No. 113-2521 Rev. 1.

directly to a two-conductor, sheathed cable. All metal parts, except the magnets and pole pieces, are Type 304 stainless steel. The insulation is high-purity (99.6% Al_2O_3) alumina. Normally, a permanent-magnet flowmeter for an instrumented subassembly is calibrated by flowtesting in a specially constructed sodium flowtest apparatus. A flowmeter so calibrated would be cleaned of sodium and its oxides before it is installed in the subassembly. The Mark-II flowmeter, however, contains crevices at end pieces welded to the main body, in which sodium can collect. Therefore, it cannot be cleaned thoroughly enough after calibration to be acceptable for use in the reactor. For this reason, the Mark-II flowmeter for instrumented subassembly XX01 was calibrated indirectly by calculation and comparison with another Mark-II flowmeter that had been calibrated directly. Its sensitivity first was calculated from the basic equation relating the induced voltage to the magnetic-flux density and flow-channel diameter. Then, the calculated value was adjusted by correction factors obtained by comparing measurements of the thickness of the flow tube, the intensity of the magnetic flux, the lengths of the magnets, and the distance between electrodes with those of the directly calibrated flowmeter. The sensitivity of the XX01 flowmeter determined in this manner was 0.312 mV/gpm at 700°F. The temperature coefficient of the flowmeter at 700°F is about -8×10^{-5} mV/gpm-°F.

There are some uncertainties in this method of calibration. One of the largest is the inadequate data for the temperature coefficient of the Alnico magnets, at 700°F, for the flowmeter in XX01. Because the performance of permanent-magnet flowmeters is largely controlled by the properties of the Alnico magnets, experiments are being made to more accurately determine the temperature coefficients of the magnets, the effects of neutron radiation on the magnets, and the long-term stability of the magnets at high temperatures.

A revised design, the Mark III, can be calibrated in sodium outside the reactor. It has no cracks or openings in the surfaces exposed to sodium and thus can be calibrated in sodium and cleaned for use in a reactor. It uses the same magnets, pole pieces, and flow tube as the Mark II and is similar in electrical performance. A Mark-III flowmeter that had been calibrated in sodium is being used in instrumented subassembly XX02, now in the reactor. This design also will be used for future instrumented subassemblies.

2. Fuel-centerline Thermocouples

The fuel-centerline thermocouple comprised four basic parts: (1) a temperature-sensing area, which extended from the fuel region to the top of a fuel element; (2) an adapter, which joined the sensing elements to (3) a hermetic seal, which coupled the adapter with (4) a pair of sheathed extension lead wires. Figure 24 shows the components of the fuel-centerline thermocouple.

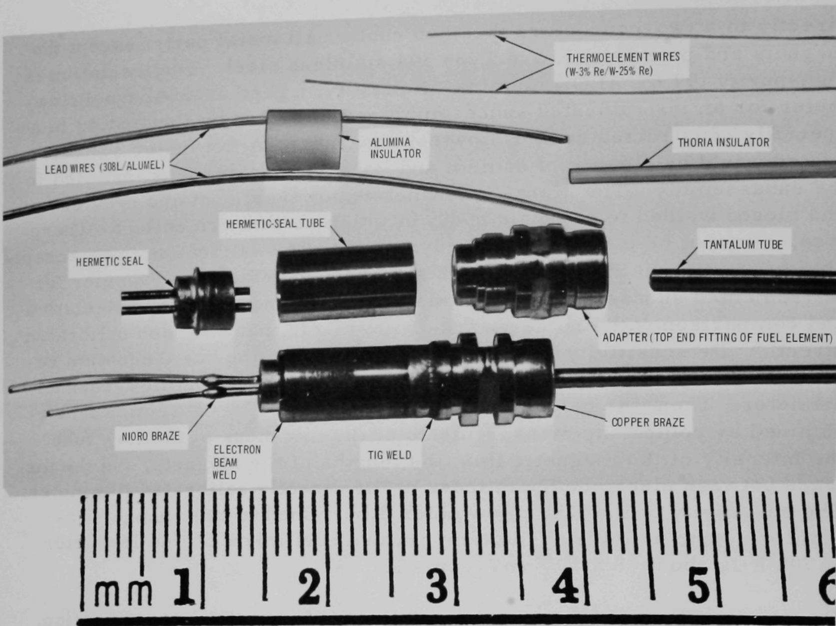


Fig. 24. Components of Fuel-centerline Thermocouple of Subassembly XX01

The temperature-sensing portion of the thermocouple consisted of tungsten-3% rhenium/tungsten-25% rhenium thermoelements (0.010 in. OD) electrically insulated with hard-fired, high-purity thoria beads (0.040 in. OD with two 0.012-in.-ID holes) and sheathed with a tantalum tube (0.063-in. OD and 0.008-in. wall). The extension lead wires were electrically insulated with alumina.

The choice of thermocouple construction and materials was based on the results of an ANL development program for fuel-centerline thermocouples. The critical portions of the thermocouples were tested out-of-pile to ensure operational safety and reliability.

Details of the assembly of the thermocouples are given in Appendix A.

3. Fission-gas-pressure Transducers

The fission-gas-pressure transducer used in XX01 (Fig. 25) is a pressure-balancing (null-balance) instrument containing two bellows. The two bellows are joined at one of their ends by a coupling disk, and their opposite ends are welded to the body of the transducer. The inside of the

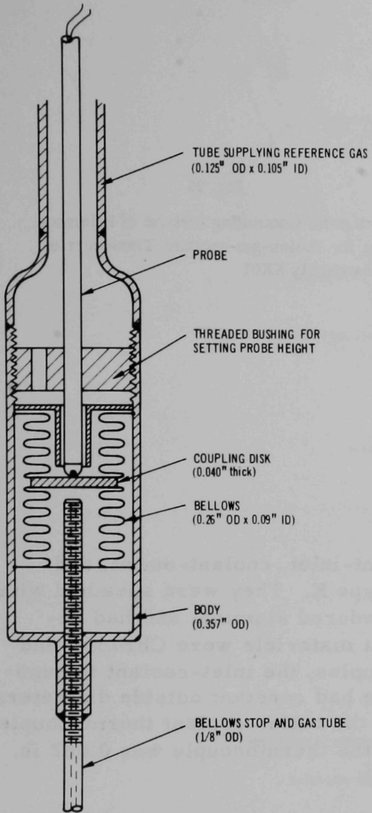


Fig. 25. Fission-gas-pressure Transducer for Subassembly XX01

lower bellows (below the disk) is connected directly to the gas space containing fission gases in the fuel element. The inside of the upper bellows (above the disk) is filled with a reference gas, the pressure of which is read directly by a gauge and indirectly, through a strain-gauge pressure transducer, by a millivolt recorder. The pressure of the reference gas is controlled (see Fig. 26) by a change in electrical resistance between a probe and the coupling disk. (The probe is a 1/16-in. thermocouple.) A rise in fission-gas pressure causes the coupling disk to make closer contact with the probe. This reduces the resistance between the probe and disk, which reduces the voltage going to the trip meters. This causes the low-trip meter to actuate its solenoid (inlet) valve, thus increasing the reference-gas pressure and forcing the disk away from the probe. This increases the resistance between the probe and disk, thereby causing the reference-gas supply to be shut off. If the resistance is decreased further, such as by a reduction in fission-gas pressure, the reference-gas pressure is reduced by opening of the solenoid (outlet) valve actuated by the high-trip meter. In this way, the reference-gas pressure is balanced with the fission-gas pressure.

This type of transducer was previously tested by ANL[5] in the laboratory for seven months at temperatures up to 1300°F and pressures up to 350 psig. Also, a transducer was tested for several months in the CP-5 reactor at a temperature of ~500°F and pressures up to 130 psig.

4. Neutron Detector

The neutron detector (or flux monitor) was positioned at the designated core elevation in a 3/16-in.-OD tube extending from the terminal box to the capsule support grid and sealed at the bottom to provide a dry-tube for the detector (see Fig. 27). The self-powered detector[6] is an insulated rhodium wire contained within a 0.063-in.-OD nickel-alloy sheath. The tube was sealed on the outside of the terminal box by a gland; the extension lead of the detector (monitor) protruded through the gland seal.

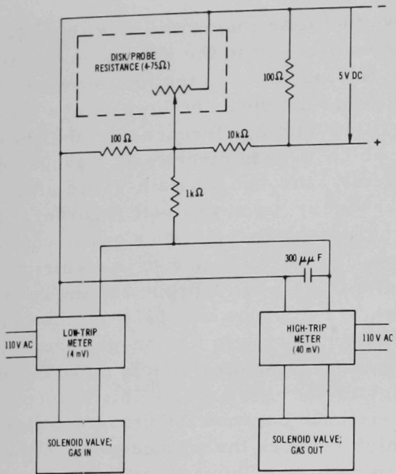


Fig. 26

System for Controlling Pressure of Reference Gas for Fission-gas-pressure Transducer of Subassembly XX01

5. Type K Thermocouples

The structural-material, coolant-inlet, coolant-outlet, and spacer-wire thermocouples were all ISA Type K. They were sheathed with Type 304 stainless steel, insulated with powdered alumina, and had ungrounded hot junctions. The thermoelement materials were Chromel and Alumel. All structural-material thermocouples, the inlet-coolant thermocouple, and one outlet-coolant thermocouple had constant outside diameters. The spacer-wire thermocouples and two of the outlet-coolant thermocouples had a swaged construction in which part of the thermocouple was 0.062 in. in OD and part was 0.040 in. in OD.

Additional details of the Type-K thermocouple are given in Appendix A.

C. Signal Transmission

1. To Terminal Box

Because the leads of the instrument sensors had to pass through liquid sodium, they were sheathed with Type 304 stainless steel. The sheathed leads entered the drywell through the drywell bulkhead, in which they were sealed by nickel-alloy brazing. Connections to nonsheathed leads were made in the sodium-free drywell (see Fig. 4) extending from the terminal box down to within about 8 in. of the top of the subassembly. The nonsheathed leads, which are flexible, fused-quartz-fiber-insulated, high-temperature signal cable, carried the sensor signals through the drywell to the terminal box. In the terminal box, the cables were connected to terminal strips (see Fig. 9). From the terminal strips, the signals were carried

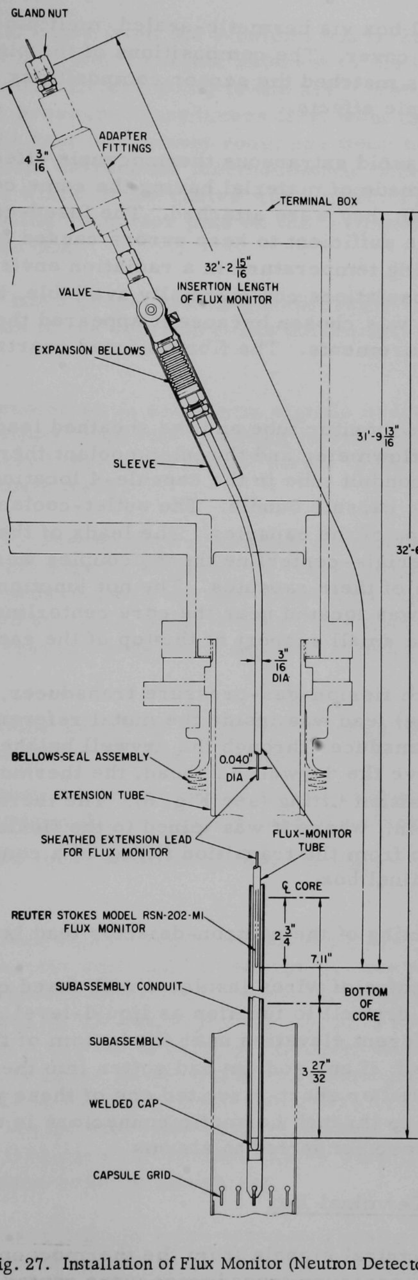


Fig. 27. Installation of Flux Monitor (Neutron Detector) in Subassembly XX01. ANL Neg. No. 104-148.

through the terminal box via hermetic-sealed, multipin receptacles mounted on the terminal-box cover. The compositions of the pins in the receptacles and of the lead wires matched the sensor compositions so as to avoid extraneous thermocouple effects.

Also to avoid extraneous thermocouple effects, the wires in the signal cables were made of material having the same composition as the sensor leads to which they were attached. The fused-quartz-fiber insulation had a resistance sufficient to keep errors caused by shunting of signals negligible at operating temperature in a radiation environment. Of the high-temperature insulations commercially available, low-boron, high-quality fused quartz was chosen because it appeared the most promising for meeting all requirements. The fibrous fused quartz was woven onto each wire.

The flux-monitor tube and the sheathed leads from the permanent-magnet flowmeter and the inlet-coolant thermocouple were routed through the conduit tube in the capsule-4 location. They left that tube at the top of the capsule bundle. The outlet-coolant thermocouples were fixed to the tops of the capsules. The leads of the fuel-centerline and structural-materials-centerline thermocouples were brazed and welded into the tops of their capsules. The hot junction of each spacer-wire thermocouple was located near the core centerline, and its sheathed lead was brazed to a small support at the top of the capsule.

For each fission-gas-pressure transducer, the metal-sheathed thermocouple (probe) lead was inside the metal reference-gas line in the routing from the transducer through the drywell bulkhead. Inside the drywell, a few feet above the drywell bulkhead, the thermocouple and gas line separated in a transition fitting (see Fig. 8). The thermocouple continued upward for about 6 in., where it was joined to the flexible leads. The gas line continued on up from the transition fitting to a compression fitting at the wall of the terminal box.

The routing of the neutron-detector lead is shown in Fig. 27.

Three pairs of wires insulated with fused quartz fiber were installed within the drywell to function as liquid-level sensors. Each pair terminated at a different elevation near the bottom of the drywell, with the wires open-circuited; if any sodium had gotten into the drywell, it would have partially shunted or short-circuited one of these wire pairs. The wires were passed up through hermetic connectors in the terminal box. From there, they were connected to alarms.

2. <u>From Terminal Box</u>

All electrical signals from the thermocouples, the flowmeter, and the fission-gas-pressure transducers were routed in shielded, multiconductor signal cable from the terminal box to 22 millivolt-to-current (MV/I) transmitters in a metal cabinet adjacent to the terminal box on the reactor operating floor. Before going to the MV/I transmitters, however, the signals from the pressure transducers first went through the reference-gas controllers in the test instrument room one floor below the reactor operating floor. To avoid extraneous thermoelectric potentials at the various wiring junctions, the wires in the cables were made of the same materials as those of the matching connector pins on the terminal box and the associated lead wires in the box.

The gas lines of the fission-gas-pressure transducers went from the terminal box to the reference-gas controllers in the test instrument room.

All instrumentation and alarm signals associated with subassembly XX01 (as distinct from fuel-handling interlocks, the up and down drive, and so on) passed through terminal strips in the metal cabinet containing the MV/I transmitters.

The MV/I transmitters converted the millivolt sensor signals to proportional current signals suitable for transmission to the recording equipment several hundred feet away and to the existing MIDAS (multiple-input data-acquisition system), which stores plant operating parameters in digital form. MV/I transmitters were selected primarily because they would:

a. Provide a current signal which would not be affected adversely by addition of other readout equipment.

b. Reduce the possibility of introducing noise signals associated with transmitting millivolt signals long distances.

c. Allow incorporation of cold-junction compensation into the transmitters.

The current signals from the transmitters first went to a terminal panel in the reactor building. From there, they went to the electrical penetrations of the reactor-plant containment, through the penetrations, and then to terminal panels in the cable-routing room. From there, they went to terminal boards in a cabinet housing strip-chart recorders in the EBR-II control room, which is in the power plant. Connections were made from these terminal boards to the strip-chart recorders and to the MIDAS; series-connected resistors transformed the current signals back into millivolt signals for recording. Ordinary instrument cables were used from the MV/I transmitters to the data-readout equipment.

Some sensor outputs were connected also to the EBR-II post-incident recall system (a system for recording selected scram-related parameters) before they had been converted into current signals by the MV/I transmitters. These connections were made in the MV/I cabinet.

The signal cables were almost always connected except during fuel handling, when the gas lines of the fission-gas-pressure transducers and all electrical-sensor signal cables were disconnected from the terminal box.

D. Data Handling and Readout

The final choices of data handling and readout involved tradeoffs between a variety of requirements, the most important of which were:

1. The requirement for a continuous record of the 22 sensor signals, for analog recording.

2. The requirement for a data record that could be analyzed easily (which implies digital equipment and digital records).

3. The desirability for redundancy by providing more than one kind of data recording.

4. The desirability of using familiar, field-proven recording equipment instead of novel schemes (important in maintenance and trouble shooting).

5. The advantages of using EBR-II equipment to the fullest possible extent.

6. The accuracy, sensitivity, speed, and flexibility of various possible analog and digital recording equipment.

7. The necessity to have readouts in engineering units so they would be immediately usable.

8. The relative costs and manpower needs associated with various kinds of readouts.

The data-readout equipment consisted of 14 analog strip-chart recorders and the MIDAS. The postincident recall system also was used to monitor selected sensor outputs, but this system was not dedicated only to logging data from subassembly XX01 and therefore is not discussed in this report. A wide-band FM tape recorder was used to record fluctuating components of sensor output signals, but this recorder was neither dedicated only to the subassembly nor continuously used and therefore is not discussed in this report either.

The strip-chart recorders were commercial units widely used in industrial plants. The charts were either 10 or 11 in. wide, thus providing easy and accurate reading of the chart record. The signals fed to these recorders ranged from 0 to 4 mA. Precision resistors at the recorder inputs converted these milliampere signals back into millivolt signals for recording. All temperatures were recorded in degrees Fahrenheit. Flow was recorded in gallons per minute on a chart paper on which the log of reactor power was also recorded. The signals from the controllers of the fission-gas-pressure transducers were recorded in millivolts on linear chart paper. These values were then converted to pressure.

Each recorder had an event-marker pen pulsed to mark every 10 min by a single time clock. Thus, the recorded traces could be related to each other on a common time scale. Dates were manually entered from time to time.

The MIDAS recorded the sensor signals as digital millivolt values and entered those values on magnetic tape along with input-channel identification and the time, day, month, and year of the sample.

During reactor startups, the strip charts of the recorders were driven at a fast speed (in some cases, at their fastest speed), and the MIDAS was operated at a rapid sampling speed. For steady-state operation, the recorder charts and the MIDAS were operated at slow speed.

So that personnel could have a periodic record of sensor performance, daily readings were made of the strip-chart and MIDAS records. A data log sheet of these readings and related plant information was prepared and distributed daily.

An annunciator panel on the recorder cabinet contained a number of alarms: "high" and "low" alarms for each of the 22 sensors and for the internal pressure of the sealed, gas-pressurized terminal box; an "on" and "off" alarm for each of the three liquid-level sensors; and an alarm for malfunction of the controllers of the fission-gas-pressure transducers.

The strip-chart recorders and the annunciators were located in the reactor control room where they could be observed by operations personnel and would be readily accessible.

Appendix H discusses checkout of the data-handling system.

E. Assembling

The subassembly, extension tube, and terminal box were assembled by (1) assembling the capsules, with their sensors, and the subassembly instrumentation into a complete subassembly unit as shown in Fig. 2; (2) attaching the subassembly to the drywell liner and brazing the leads into the bulkhead of the liner (called bulkhead brazing); (3) connecting the instrument leads in the drywell region to extension leads and securing these leads to the drywell liner; (4) completing the attachment of the extension leads by installing coupling components; and (5) attaching the terminal box to the extension tube and terminating the leads within the box.

All assembling was done according to step-by-step, detailed procedures. To ensure that no instrument sensor had been damaged, instrumentation installed was tested after critical assembling steps. These tests are discussed briefly in Sec. 4 below and in more detail in Appendix E.

1. Assembling the Subassembly

The stainless steel-sheathed sensor leads from the capsules were cut to a length slightly more than the final length required. The sheaths were stripped back and deburred. Then, some ceramic insulation was removed from the lead end, and the end was immediately sealed with moisture-proof resinous material. This seal was maintained until immediately before the extension leads were attached to the sensor leads.

All capsules and subassembly parts were degreased with trichlorethylene, wiped with ethyl alcohol, and air-dried. Capsules 1 through 3 and the conduit tube for capsule position 4 were placed on the T-bars of the grid assembly. The flowmeter was then threaded through the grid assembly and into the tip of the conduit tube until the flowmeter was properly located in the grid assembly. The flowmeter was then plug-welded to the grid assembly. The remaining capsules were then installed in numerical sequence on the grid assembly. The lower adapter was inserted into the grid assembly and plug-welded. The outer hexagonal tube of the subassembly was slipped over the capsule bundle and grid assembly until it was fully seated over the lower adapter. The lower adapter was then plug-welded to the hexagonal tube.

The instrument leads were threaded through the top end adapter, and the adapter was fully seated in the outer hexagonal tube. The adapter was then plug-welded to the hexagonal tube.

The subassembly was weighed. Then it was given a tensile test in which a 2000-lb tensile force was applied to the subassembly in increments while the elastic elongation was shown on a dial indicator. The subassembly passed the tensile test: After release of the tensile load, the dial indicator returned to its initial position, the subassembly had retained its original dimensions, and no failure was observed.

2. Attaching Subassembly to Drywell Liner

This step includes passing the instrument leads through the bulkhead of the drywell liner and sealing them to the bulkhead by brazing according to the procedure condensed in Appendix C. The bulkhead for subassembly XX01 contains 23 penetrations: 17 of 0.062-in. diameter for the sheathed thermocouples; one of 0.125-in. diameter for the flowmeter lead; four of 0.125-in. diameter for the tubes of the fission-gas-pressure transducers; and one of 0.187-in. diameter for the flux-monitor tube.

The bulkhead and the sheathed leads from the subassembly were precleaned. The bulkhead was cleaned ultrasonically, and the portion of each lead that would be brazed into the bulkhead was scoured with aluminum oxide and water, after which the leads were wiped with a cloth soaked with ethyl alcohol and air-dried.

With the subassembly horizontal, the slide piece (the bottom 12 in. of the extension tube up to the bulkhead) was placed over the top adapter, and the instrument leads were threaded through the bulkhead. A device was installed for holding the bulkhead and the instrumented subassembly in position during subsequent welding, brazing, and wiring.

The brazing furnace (Fig. 28) was designed to be evacuated to 5×10^{-5} Torr and to braze at 1 atm of hydrogen. To keep the temperature in the braze zone uniform, an iron susceptor was used to heat the nonregular cross section of the bulkhead. Figure 29 shows the brazing chamber without the susceptor and with the bulkhead within the induction coil of the chamber.

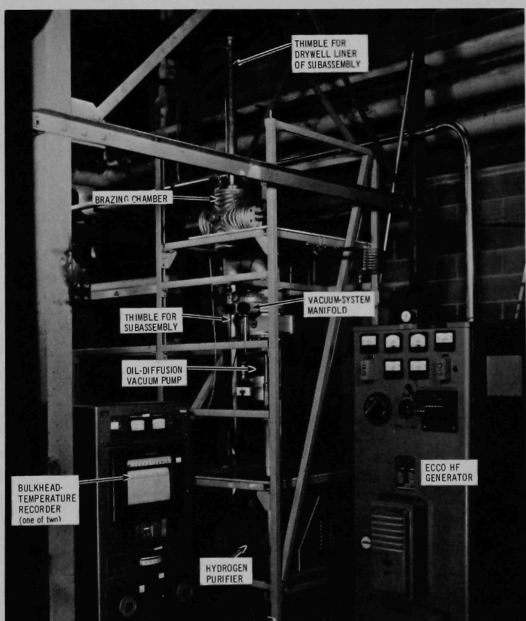


Fig. 28. Brazing Furnace for Subassembly XX01. ANL Neg. No. 113-1054A.

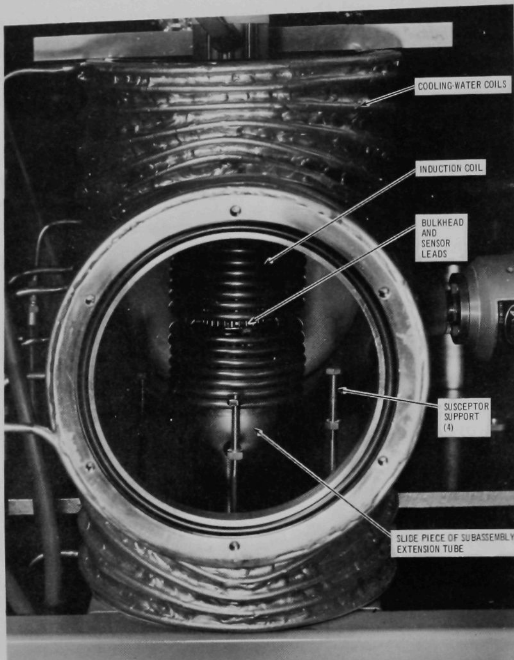


Fig. 29. Drywell Bulkhead in Induction-heated Brazing Chamber of Brazing Furnace (viewing cover removed). ANL Neg. No. 113-1057A.

All sensor leads were brazed simultaneously. For all penetrations to braze consistently, the preassembly of the bulkhead and leads was cleaned with a hydrogen atmosphere, while heated, in the furnace. With the preassembly in the furnace, air was removed from the furnace by evacuating and purging it with argon four times. Then, the furnace was again evacuated, pure hydrogen was fed into it to a pressure of 5-15 in. H_2O, and a flow rate of 4-5 liters/min of hydrogen through the furnace was established and maintained. Then, the bulkhead was heated to 2156°F for 3 min. The work was then cooled in the flowing hydrogen, the hydrogen was replaced with argon, and the furnace was opened. Braze alloy was then placed into the cavities around the instrument leads in the bulkhead, and the furnace was made ready for the braze cycle by evacuating and purging as above. Then, the braze was made with the bulkhead heated to 2156°F.

The braze alloy chosen to make the bulkhead seals was a high-nickel, chromium, silicon alloy (Coast Metal 60), which is compatible with sodium at the temperatures encountered in EBR-II. Its nominal composition and working temperatures are:

Nominal Composition, %		Working Temperatures, °F	
Chromium	20.00	Solidus	1975
Silicon	10.00	Liquidus	2075
Iron	3.00	Brazing temp	2150
Nickel	Balance		

After the brazing, the subassembly was removed from the furnace, and the top surface of the bulkhead was examined for evidence of braze flow and wetting. The subassembly with the slide piece was then placed in a leak-detection fixture, and each penetration was examined for leaks with a helium-sensitive, mass-spectrometer leak detector.

3. Completing the Assembly

The tubes of the fission-gas-pressure transducers and the tube of the flux monitor were coupled to connecting tubes by sleeves which were induction-brazed to the tubes with an 82% gold-18% nickel braze alloy. The brazed joints were helium-leak-checked; the maximum acceptable leak rate was 1×10^{-8} cc (STP) of helium per second. The sheathed leads from the thermocouples and the flowmeter were cut to the final length required, flexible extension lead wires were joined to them by resistance welds, and the connections were surrounded by ceramic insulators. Then, the extension leads and the wires that would detect any leakage of sodium into the drywell were strapped down to the drywell liner. Next, two drywell annular spacers were tack-welded to the outside of the drywell liner. These spacers, one 7 ft from the top of the liner and the other 19 ft from the top, maintain a fixed annulus between the liner and the outer extension tube. The upper spacer also supports the shielding steel shot, which is poured to a depth of 40 in. in the annulus. Before the shot was poured, a small (0.125-in.-OD x 9-in.-long) tube was strapped to the outside of the liner so that about 4 in. of the tube would extend down into the shot. This tube extends through the nonporous silicone rubber shot retainer poured later (see below) and provides for passage of gas from the region below the shot during evacuation of the drywell and subsequent leak testing.

The outer extension tube then was slipped over the wired drywell liner and welded to the periphery of the drywell bulkhead. The drywell annulus was evacuated, and the weld was leak-checked with helium; the maximum acceptable leak rate was 10^{-8} cc (STP) of helium per second.

The subassembly and attached extension were raised to vertical, and about 5.5 lb of the shielding shot was poured into the annular space between the drywell liner and extension tube in the region above the upper annular spacer. A layer of silicone rubber was applied to the top of the shot and allowed to cure. Then, the subassembly and extension were returned to horizontal.

The holding device used during brazing was removed from the assembly, a preassembly of a coupling, coupling sleeve, and release rod was installed within the drywell liner, and the coupling was coupled to the top adapter of the subassembly. Then, the drywell-liner flange, containing the static and sliding O-rings for sealing the gas atmosphere of the terminal box and drywell (see Fig. 4), was installed at the top of the drywell liner. Next, the coupling-support parts were installed.

Then, the tubes of the fission-gas-pressure transducers and the tube of the flux monitor were connected to their appropriate end fittings in the terminal box, the flexible extension lead wires were connected in the box, and the covers were attached to the box. (The procedures for making the wiring connections in the drywell and terminal box are described in Appendix D.)

A complete external-measurement inspection of the completed assembly was made, primarily as assurance that there would be no interference when installing, removing, and handling the subassembly within the reactor. The measurements were inserted on a control drawing (Fig. 30) and on a control sheet which listed 34 measurements and other observations to be checked.

The instrumented subassembly was then installed into its shipping container.

4. Tests of Instrumentation

During the entire assembling operation, each subassembly instrument was periodically tested to determine whether it remained functional. In general, tests were made after each welding or brazing operation and after extensive handling. The object of frequent testing was to determine damage as early as possible, so optimum corrective action could be applied.

The assembling procedures for the subassembly and the extension tube explicitly indicated where the instrument tests were to be performed and which part of the separate instrument-test procedures (see Appendix E) were to be used. The test procedures used for the instruments are briefly described in the five subsections immediately following.

a. Thermocouple Tests. The two basic thermocouple tests were measurements of the resistance of the thermocouple loop (wire-to-wire) and of the insulation (wire-to-sheath). Because the thermocouples had ungrounded junctions, the insulation-resistance test could be used to determine the quality of the insulation. A thermocouple was assumed functional if the two resistances were found to be as expected. (The expected resistance values were previously measured values corrected for removal or addition of thermocouple wire and insulation and for effects of changes in humidity and temperature.) Voltages for testing insulation resistance were kept low to prevent any damage to the insulation (i.e., 50 V dc for out-of-reactor measurements and 10 V dc for in-reactor measurements).

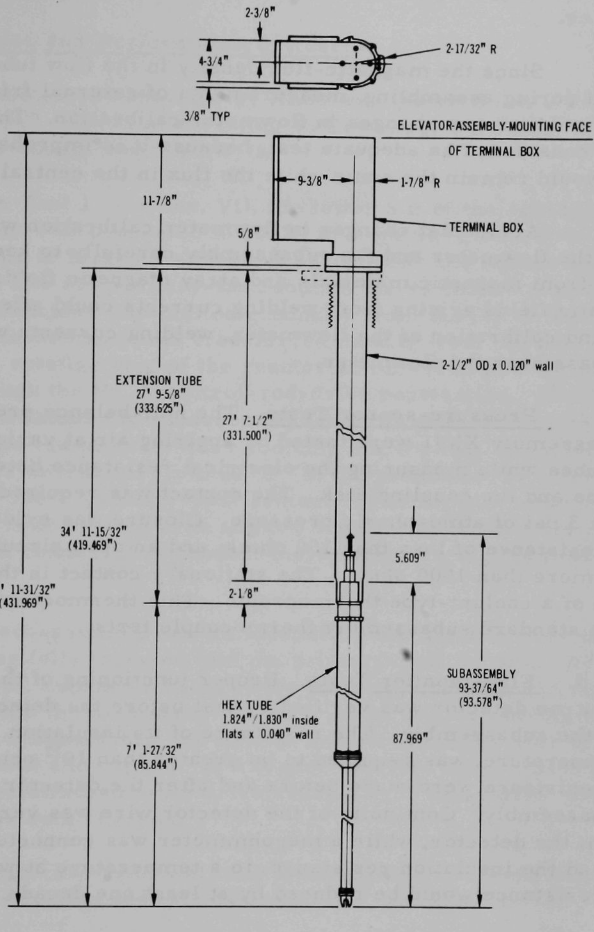


Fig. 30. Postassembly Measurements of Subassembly XX01

b. Flowmeter Tests. Measurements of the flowmeter loop resistance (wire-to-wire), the two wire-to-sheath resistances, and the fringe magnetic-flux density were used to determine the condition of the flowmeter during and after assembly.

Because the flowmeter was grounded, its insulation resistance could not be measured directly. However, it was assumed to be comparable to that of the resistance of the thermocouple insulation. This assumption was considered valid because of the similarity of insulation materials and assembling procedures for the flowmeter and the thermocouples.

Since the magnetic-flux density in the flow tube could not be measured during assembling, measurements of external fringe flux were relied upon to detect any changes in flowmeter calibration. These measurements were considered an adequate test, because it is improbable that the fringe flux would remain the same while the flux in the central tube changed.

Accidental changes in flowmeter calibration were prevented by handling the flowmeter and the subassembly carefully to keep the flowmeter away from magnetic materials and stray magnetic fields. Because stray magnetic fields arising from welding currents could affect the magnetic field and calibration of the flowmeter, welding currents were not allowed to pass near the flowmeter.

c. Pressure-sensor Tests. The null-balance pressure sensors in subassembly XX01 were tested by applying air at various pressures to the gas tubes while measuring the electrical resistance between the stationary probe and the coupling disk. The contact was required to open and close within 3 psi of atmospheric pressure. Closure was evidenced by a measured resistance of less than 100 ohms, and an open circuit by a resistance of more than 1000 ohms. The stationary contact in the probe was the junction of a coolant-type thermocouple. This thermocouple was tested by using the standard subassembly thermocouple tests.

d. Flux-monitor Tests. Proper functioning of the self-powered neutron detector was verified by test before the detector was inserted into the subassembly. The resistance of its insulation, measured at room temperature, was required to be greater than 10^{12} ohms. Tests of insulation resistance were made before and after the detector was inserted into the subassembly. Continuity of the detector wire was verified by heating the tip of the detector, while a megohmmeter was connected and adjusted to read the insulation resistance, to a temperature at which the insulation resistance would be reduced by at least one decade.

e. Tests with a Time-domain Reflectometer. A time-domain reflectometer (TDR) was used to examine each instrument in the subassembly as an aid to locating instrument failures. The TDR applies a step-voltage signal to the end of a transmission line and displays the reflected wave form of the voltage. The reflected wave form indicates the magnitude and position of impedance discontinuities along the length of a transmission line. When used to examine subassembly instruments, the reflected wave form indicates the position of all lead-wire and instrument discontinuities.

A failed instrument will show an abnormal discontinuity at the site of the failure. The TDR was very successful in locating instrument failures in the subassembly.

F. Installation and Performance in Reactor

Instrumented subassembly XX01 was inserted into EBR-II in mid-November 1969 and began operating on December 17, 1969. Its maximum linear power rating was ~10 kW/ft.

As in Test 1 (see Sec. VI), the lower 8 ft of the subassembly and its extension tube was preheated to 600°F in a special heater before insertion. This was done to lessen the thermal shock while the subassembly was being inserted into the primary-tank sodium and to ensure that the sodium bond in the capsules was melted gradually from the top to the bottom. The preheated subassembly was transferred rapidly from the heater to the top of the small rotating plug of the reactor and lowered into the primary-tank sodium through the No. 6 control-rod-drive penetration. About 4 min were required to transfer the subassembly from the preheater and submerge its lower 8 ft into the primary-tank sodium. During this time, the capsule temperatures decreased from 600°F (in the preheater) to 545°F just before entering the 580°F primary-tank sodium. (The capsule temperatures were indicated by four spacer-wire and two structural-capsule thermocouples that had been connected to readout instruments during the preheating and transfer.)

The subassembly and its extension tube initially were held 60 in. short of being fully inserted into the primary-tank sodium. At this point, the differential expansion between the four-jaw coupling and the extension tube was within the displacement limits of the support spring (see Figs. 4 and 7). The subassembly was held at this elevation for 5 hr to allow the coupling to heat and expand. It was then inserted fully. After the subassembly was attached to its drive assembly, it was raised and lowered several times as a checkout.

Mechanical, electrical, and instrumentation checks and tests were made before, during, and immediately after installation.

For about 10 days before the initial reactor startup, a series of tests was run with various sodium flows and temperatures to provide: (a) in-reactor empirical calibration of the sensors before they were exposed to high radiation levels; (b) final checkout of the data-readout equipment before reactor startup; and (c) preirradiation testing of the sensors.

The initial startup was made in gradual, stepped increments of reactor power. This was good engineering practice, because subassembly XX01 was the first instrumented subassembly for power operation. Subassembly operation could be observed and sensor data could be read and recorded during the rise to power. Table V summarizes data taken from strip-chart recorders during the initial startup, at the various incremental power levels.

TABLE V. Data from Instrumented Subassembly XX01 during Initial Startup of Reactor

(all values in °F unless otherwise indicated)

Sensor Type[a]	Capsule Position	Reactor Power, MWt: 0.500	10	15	20	25	30	35	40	45	50
FCTC	1	743	1033	1185	1333	1482	1650	1789	1945	2093	2246
FCTC	2	741	1076	1245	1414	1580	1742	1918	2100	2250	2417
FCTC	3	729	1108	1288	1470	1643	1832	1976	2174	2336	2507
FCTC	7	702	1049	1211	1373	1530	1702	1845	2008	2142	2300
FCTC	10	702	1026	1180	1324	1465	1620	1755	1902	2032	2187
FCTC	15	694	1045	1206	1360	1508	1672	1810	1962	2116	2269
FCTC	17	707	1018	1170	1319	1458	1612	1733	1868	1994	2134
SWTC	3	702	714	723	732	739	748	757	766	777	786
SWTC	7	702	720	727	734	739	748	756	763	763	779
SWTC	10	702	730	743	756	768	784	793	804	820	831
SWTC	17	698	727	738	756	761	774	786	801	811	824
ITC	4	694	696	694	694	694	693	693	694	694	693
OTC	5	698	727	738	750	763	775	786	801	811	824
OTC	14	705	732	743	757	766	779	797	810	819	829
STR.TC	8	691	725	739	754	770	786	801	815	833	847
STR.TC	19	696	730	747	763	779	793	806	820	838	851
Flowmeter, gpm		28.4	28.4	28.2	28.2	28.2	28.2	28.2	28.2	28.1	28.1

[a]FCTC = Fuel-centerline thermocouple; SWTC = Spacer-wire thermocouple; ITC = Inlet-coolant thermocouple; OTC = Outlet-coolant thermocouple; and STR.TC = Structural-material-centerline thermocouple.

Appendix G summarizes the procedure for conducting tests of subassembly XX01 before and during reactor startup, Appendix I the procedure for operating XX01 in the reactor, and Appendix J the procedures for fuel handling while XX01 was in the reactor.

Table VI gives typical data taken during three reactor runs for all instrumentation except the self-powered neutron detector. Appendix K gives continuous graphs of the readings of selected sensors throughout the entire irradiation period.

The overall accuracy of the readout instrumentation (sensors, transmitters, and recorders) was such that temperatures were recorded to within approximately 1% of the thermocouple-junction temperature and coolant flow rates to within approximately 4% of the estimated flow rate.

All measured values except temperatures at the fuel centerlines were very close to the expected values. Measured temperatures at the fuel centerlines were lower than anticipated. Experimental goals for fuel-centerline temperatures had initially been directed toward 2800-3600°F. Because of conservatism in design calculations, however, actual temperatures were 2100-2500°F.

TABLE VI. Data from Instrumented Subassembly XX01 for EBR-II Runs 39, 40, and 41

Conditions

Reactor power	50 MWt	Hours at power	1989.5
Primary-sodium temp	700°F	Approximate burnup	1 at. %
Reactor outlet temp	847°F	Time in reactor	11/19/69 to 4/11/70
Primary flow	100%	Number of reactor fuel loadings	6 (excl. install. and removal of XX01)

Sensor Type[a]	Capsule Position	Temperatures, °F Run 39 (12/17/69 to 1/28/70) At Start	At End	Run 40 (1/28/70 to 3/1/70) At Start	At End	Run 41 (3/5/70 to 4/1/70) At Start	At End
FCTC[b]	1	2246	2201	-	2143	2147	2165
FCTC[c]	2	2426	2372	2327	2336	2236	
FCTC[d]	3	2516	2453	2408	2372	2336	-
FCTC	7	2300	2192	2147	2138	2134	2138
FCTC	10	2192	2125	2098	2093	2093	2066
FCTC	15	2282	2228	2214	2215	2201	2210
FCTC[e]	17	2138	2070	2244	2230	-	-
SWTC	3	790[f]		790[f]		784[f]	
SWTC	7	775		775		756	
SWTC	10	830		828		824	
SWTC	17	824		815		810	
ITC	4	700		693		698	
OTC	5	824		806		833	
OTC	6	826		820		829	
OTC	14	815		810		820	
STR.TC	8	852		844		842	
STR.TC	19	850		838		824	
Flowmeter		28.0 gpm		28.0 gpm		27.5 gpm	

[a]FCTC = Fuel-centerline thermocouple; SWTC = Spacer-wire thermocouple; ITC = Inlet-coolant thermocouple; OTC = Outlet-coolant thermocouple; and STR.TC = Structural-material-centerline thermocouple.
[b]Defective 1/31/70 to 2/21/70.
[c]Defective on 3/6/70, but recorded on 3/8/70 and 3/9/70, when value appeared reasonable for short period.
[d]Became defective 3/7/70.
[e]Became defective 3/1/70.
[f]This and the values following are typical for the run.

The average heat rating of the fuel elements in the instrumented subassembly was in the range from 8 to 9 kW/ft. At this low heat rating, calculations predicted essentially zero release of fission gas during operation and an internal pressure of 40 psia in the fuel element. The four measured internal pressures ranged from 35 to 44 psia, and each was essentially constant throughout the test; these values are in agreement with the calculated pressure. (A pressure of 60 psia was estimated for 100% gas release.)

During the initial EBR-II reactor heat-up and run at full power, the reference-gas pressures of the four fission-gas-pressure transducers were recorded at outlet-coolant temperatures of 375, 400, 700, and 850°F. The recorded pressures were compared with the calculated pressures in the fuel elements for these temperatures. The pressure transducers gave no indication of buildup of fission-gas pressure during the entire period of irradiation of the subassembly. When the reactor was shut down and the pins cooled, the transducers responded to the cooling consistently and without being erratic.

A postirradiation examination of a pressure transducer is planned. The element plenum to which it was attached will be punctured to determine its internal pressure for comparison with the measured pressure of the reference gas. The transducer will be recalibrated for comparison with its initial calibration.

The self-powered neutron detector performed as expected. Its output currents measured during reactor operation were in close agreement with calculated values.

The instrumented subassembly was in the reactor for 140 days, during which time it was irradiated for 3856 MWd of reactor operation.

The general status of sensor readouts during the irradiation is shown in Fig. 31. The readouts from three (No. 7, 10, and 15) fuel-centerline thermocouples were normal for the duration of the test. The readouts from the other four were characterized by intermittent and/or erratic behavior at various times. The break in the readout from one of the four (No. 1) was traced to malfunctioning of data-handling electronics. The other three thermocouples (No. 2, 3, and 17) had apparently failed. Time-domain-reflectometer (TDR) tests made while the subassembly was in the reactor, however, indicated that the failures had occurred not in the thermocouples, but in the region of the drywell where the sheathed leads were joined to the extension leads. After the TDR tests, the readout from thermocouple No. 2 indicated recovery.

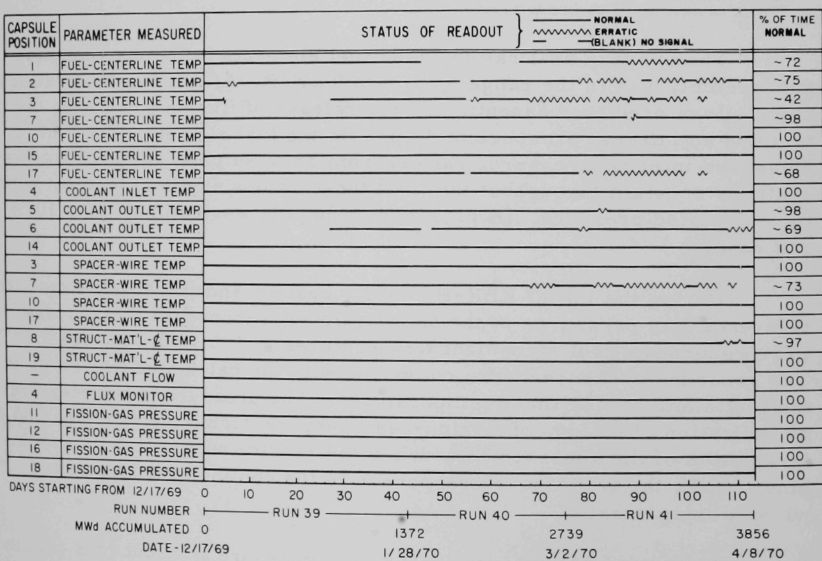


Fig. 31. Status of Sensor Readouts from Subassembly XX01

TDR measurements indicated that the apparent failure of outlet-coolant thermocouple No. 6 was also in the drywell region. The location and mode of the apparent failure of spacer-wire thermocouple No. 7 could not be definitely diagnosed by TDR.

G. Removal from Reactor

Instrumented subassembly XX01 was removed from the reactor according to the procedure described in Appendix L.

The terminal box was removed, and the coupling-and-gripper assembly was raised into a pulling pipe such as customarily used for removing main shafts of control rods. With the assembly in the pipe, a radiation level of 30 R was measured 6 in. from the outer surface of the pipe, at the elevation of the lower end of the assembly.

Removal of the coupling-and-gripper assembly left an opening through the drywell liner, which extended from the operating floor to the top of the subassembly, some 27 ft below. A cutting tool attached to a long shaft was lowered through this opening and made to rest on the top of the subassembly. The tool consisted of two cutting blades 180° to each other on the periphery of a hollow shaft of tool steel (AISI-SAE-TI) hardened to Rockwell C-58. During insertion, the blades were guided within the major axis of the drywell liner. During the last few inches of insertion, a free-floating sensing rod within the hollow shaft (see Fig. 17) contacted the top end fitting of the subassembly. To properly seat the cutting tool at its cutting location, the hollow shaft was lowered until an indicating mark on it lined up with a corresponding mark at the top of the sensing rod.

In subassembly XX01, 23 leads and tubes with diameters of 1/16 to 3/16 in. were cut by rotating the cutting tool 180° with its electric drive motor. The cutting edges are offset 15° from the diameter of the tool to provide a shearing action which tends to reduce cutting torque and deflect a cut lead outward so that it will not interfere with the next lead to be cut. The cutting torque was recorded, and the cutter position was followed on a recorder chart. Figure 32 shows the curve of torque versus angular displacement obtained when cutting the leads. The torque varies in accordance with the diameter of the lead or tube being cut. In the first 60° of cutter rotation, four peaks of torque occurred. The first, second, and fourth were caused by cutting three pairs of 1/16-in.-dia sheathed leads. The third was caused by cutting a pair of 1/8-in.-dia tubes. The other two groups of peaks, although not as definite as the first, show the higher torques caused by cutting 1/8- and 3/16-in.-dia tubes. The chart was of primary significance for detecting abnormalities and the sequence of the cuts while the cutting operation was taking place.

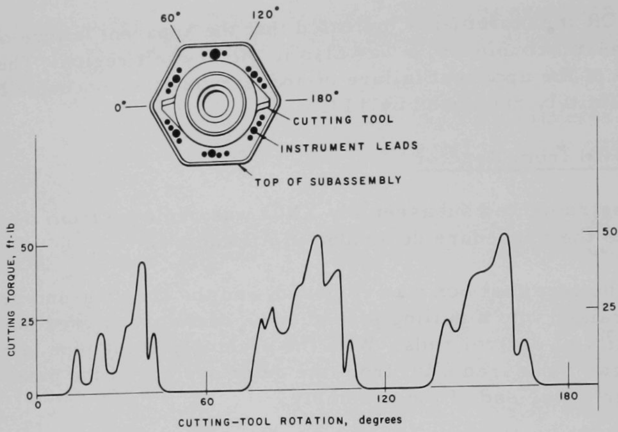


Fig. 32. Record of Lead Cutting for Subassembly XX01.
ANL Neg. No. 104-150 Rev. 1.

The final step of separation consisted of removing (by lifting) the extension tube and cutting tool as one unit while leaving the subassembly in the reactor. The sensing rod remained in contact with the top end fitting of the subassembly during the first 6 in. of upward travel of the extension tube and tool. Complete separation of the subassembly and extension tube was indicated by observing that the indicating mark on the hollow cutting-tool shaft moved upward while the indicating mark on the rod remained at the same elevation.

The extension tube, cutting tool, and sensing rod were raised into the pulling pipe and allowed to drip and cool. A gate valve attached to the bottom of the pulling pipe, and another gate valve directly below on the bellows flange, were then closed. The top valve sealed the pulling pipe, and the bottom valve sealed the opening to the primary tank. The pulling pipe and its contents were then removed to the previously designated storage location.

With the extension tube, cutting tool, and sensing rod raised into the pulling pipe, the radioactivity of the lower 2 ft of the extension tube was measured as 200 R at 6 in. from the outer surface of the pulling pipe.

H. Postirradiation Examination and Testing

Postirradiation examinations and tests were preplanned to obtain meaningful guidance for subsequent instrumented subassemblies. This work centered on the lower portion (about 54 in. long) of the extension tube, which was sawed off after removal, and on the subassembly and its contents.

A limited wash procedure was specified to keep the subassembly as free from water damage as possible. Moist argon was used instead of water to deactivate the sodium surfaces of the subassembly after it had been taken from the storage basket in the primary tank of the reactor. Even so, the subassembly was coated with a heavy layer of sodium reaction products after this step. Thus, for future cleaning of instrumented subassemblies, additional wiping with a moist cloth may be necessary.

1. Lead Wires and Connections in Extension Tube and Drywell

The lower 54 in. of the extension tube was of interest because the connections of the sensor leads to the flexible lead wires are in this region. These connections, located in the drywell between the extension tube and the drywell liner, could be examined only after removing the extension tube (also called the outer tube). To remove the outer tube, it was first cut with a pipe cutter at the brazed drywell bulkhead. Cutting and subsequent handling were done in the air cell because of the radioactivity of the parts.

When the outer tube was being removed for exposing the lead-wire connections, a 0.002-in.-thick stainless steel sheet, which had been placed over the connections for protection during assembling, caught on the cut edge of the outer tube. This caused the thin sheet to crumple and partially fill the drywell annulus between the outer tube and the drywell liner, thereby damaging the flexible leads to such an extent that proper evaluation could not be made.

The color of the quartz insulation of the sodium-level-sensor leads had changed from the original white to black from the bulkhead to a point about 20 in. above it. Above the 20-in. point, the black gradually faded until the color was the original white 30 in. above the bulkhead.

The hard-fired alumina insulators that insulated the wire connections did not appear to have changed color. The inspection was made under incandescent light and through a periscope.

It is assumed that the color changes were caused by nuclear radiation. It should be noted, however, that radiation-induced changes in the color of an insulator are not necessarily strongly correlated with resistivity changes. Attempts will be made to determine the relationship between the color changes and any resistivity changes caused by the reactor environment when the required resistivity data become available.

From the observations reported above, it appears that the nuclear radiation in the subassembly drywell was significantly reduced at levels exceeding 30 in. above the bulkhead. This suggests that insulating materials whose radiation tolerance is not clearly defined or which have less radiation tolerance than quartz, alumina, or magnesia should be used no lower than 30 in. above the bulkhead.

To evaluate the integrity of the brazes of the sensor extension leads to the bulkhead, the bulkhead was sectioned and three brazes were examined metallographically. The examinations showed that the integrity of the brazes had not been impaired by the exposure to sodium, high temperature, and irradiation.

2. Subassembly and Contents

a. Visual Examination. The subassembly was visually examined and photographed through a window of the air cell. No unusual features or anomalies were discovered, other than the remaining layer of sodium reaction products. This heavy coating prevented taking the routine measurements for straightness and flat-to-flat dimensions on the flats of the hexagonal tube.

After the visual examination and photography, the top adapter and the hexagonal tube were removed so the capsules could be removed from the grid. Each capsule was removed carefully while its grid position and identification number were noted to confirm agreement of the loading diagram with the assembling diagram. Close visual inspection through a periscope disclosed no anomalies, other than sodium reaction products on the capsule surfaces.

b. Neutron Radiography. All 18 capsules were neutron-radiographed by the standard technique used for other EBR-II capsules and elements. Particularly of interest were the condition of the fuel-centerline and spacer-wire thermocouples and any indications of gross relocation of fuel, formation of central voids in the fuel, and cracking or gross failure of the element cladding. The radiography was performed successfully, and no anomalies were observed.

c. Decay-heat Measurements and TDR Tests of Sensor Continuity. Plans had been made to use the fuel-centerline thermocouples for measuring decay heat and to make TDR tests of the electrical continuity of some of the sensors. However, difficulty was encountered in removing the sheathing from the severed ends of the sensor leads to connect them to readout equipment. A technique with new stripping fixtures has performed satisfactorily out-of-cell, but could not be fully developed in time for removing the sheathing of the XX01 leads.

d. Testing of Flowmeter. To determine whether the magnetic-flux density of the flowmeter had been changed with irradiation, postirradiation measurements of the density were made in the air cell.

Removal of the fuel elements and the grid of the subassembly exposed the flowmeter. A probe attached to an Empire Model 900 gaussmeter was inserted to a depth set by a spacing insert into the flow channel of the flowmeter and rotated until a maximum reading was obtained. This was done twice; one reading was 706 G, and the other was 710 G.

Both readings are lower than the measured preirradiation magnetic-flux density of 740 G, even when allowance is made for the 3% rated accuracy of the flux-testing instrumentation. However, the postirradiation readings were taken at a temperature (in-cell) of 104°F, which is about 30°F higher than the temperature at which the preirradiation readings were taken. The higher temperature could have affected the sensitivity of the probe. Plans are to calibrate a probe at different temperatures to evaluate the apparent downward shift of the flux.

The readout from the flowmeter during the irradiation did not indicate that the strength of the magnetic field was decreasing.

e. Calibration of Neutron Detector. Postirradiation calibration of the neutron detector of the flux monitor was impossible because of its high radioactivity. However, a calibration test conducted in the Argonne Fast Source Reactor (AFSR) on an identical detector substantiated the relationship of output current to flux.

The test in subassembly XX01 (and also in the AFSR) verified the value of this type of detector for measuring flux in a high-temperature, fast-flux environment. Postirradiation neutron radiographs of the detector showed no impairment of its integrity by the severe environment.

f. Additional Tests. Capsules 2, 7, 8, 12, and 19 will be destructively examined. Capsules 2, 7, and 12 are fueled capsules; capsules 8 and 19 are structural-material capsules.

The elements in capsules 2 and 7 both contain fuel-centerline thermocouples and are identical in power rating and all design respects, except that the element in capsule 2 contains helium as the fill gas and the element in capsule 7 contains an 85 He-15 Xe wt % mixture of helium and xenon. Strangely, the element in capsule 2, despite the higher-conductivity gas in its annulus, operated with a significantly higher fuel-centerline temperature than the element in capsule 7 (2340 versus 2150°F). The element in capsule 7 has a well-characterized temperature history, because the capsule was wrapped with a spacer-wire thermocouple. It showed the largest decrease in fuel-centerline temperature with time of any element measured for this temperature. This decrease could be indicative of closure of the fuel/cladding gap, fuel sintering, or progressive failure of the thermocouple.

The element in capsule 12 contains a pressure transducer, but no fuel-centerline thermocouple. The in-pile measurements of the transducer will be compared with postirradiation volume/pressure measurements of gases collected from the element plenum. The microstructures of the solid-pellet fuel in this element will be compared with those of the annular-pellet fuel in the elements of capsules 2 and 7 to assess the effects of the fuel-centerline thermocouples on the temperature distributions in the fuel. Of the four elements with pressure transducers, the element in capsule 12 was closest in operating conditions to the elements in capsules 2 and 7.

Plans have also been made to analyze gas samples from xenon-tagged elements 7 and 12. Possible changes in tag ratios will be measured.

The element in capsule 3 will be held in reserve for possible subsequent study. This element operated at the highest fuel temperature (about 2370°F), but its fuel-centerline thermocouple was erratic. If the elements in capsules 2 and 7 show evidence of fuel restructuring, there could be interest in examining the element from capsule 3.

The destructive examination of the fuel elements is expected to provide information related to the kinetics of closure of the fuel-cladding gap, fuel restructuring or sintering, and the effects of fission gas on conductance of the fuel/cladding gap. These examinations should be valuable for assessing the early stages of mechanical and chemical interactions of fuel and cladding and for relating the behavior of fission gas to fuel swelling.

VIII. CONCLUSIONS

The EBR-II instrumented-subassembly system has demonstrated its capability for continuous monitoring of experiments within the core region of a fast breeder reactor. The test irradiation of the first fueled subassembly for 140 days (3856 MWd) showed that the instrumented subassembly as an experimental-irradiation vehicle is fully compatible with the existing reactor systems and that it can be readily installed, handled, and removed during routine reactor shutdowns.

Besides demonstrating the compatibility of the instrumented-subassembly system, the test also demonstrated the adequacy of a number of in-core instruments and measuring techniques and the overall capability for transmitting pneumatic and electrical signals from the subassembly to readout equipment. The spacer-wire thermocouples, the inlet- and outlet-coolant thermocouples, the self-powered neutron-flux monitor, the fission-gas-pressure transducers, and the permanent-magnet flowmeter all performed well and gave readings close to the expected values. Of the seven fuel-centerline thermocouples, four were still operating fully satisfactorily at the conclusion of the test. All thermocouples, however, remained structurally sound. The apparent failures of the three were due to breakage of extension wires, because of differential expansion, in the splicing region of the drywell.

A second instrumented subassembly (XX02) is being irradiated now for over 10,000 MWd in the reactor, a third is being constructed for installation immediately after the removal of XX02, and additional experiments with instrumented subassemblies are being planned. Information from these instrumented subassemblies is expected to be of significant value to the liquid-metal-cooled fast-breeder-reactor program.

APPENDIX A

Assembling Thermocouple Sensors for Subassembly XX01

1. Fuel-centerline Thermocouples

The seven fuel-centerline thermocouples for subassembly XX01 (see Fig. 33) were assembled at ANL. All thermocouple components were either obtained from commercial sources or made by ANL, and were of known and documented quality.

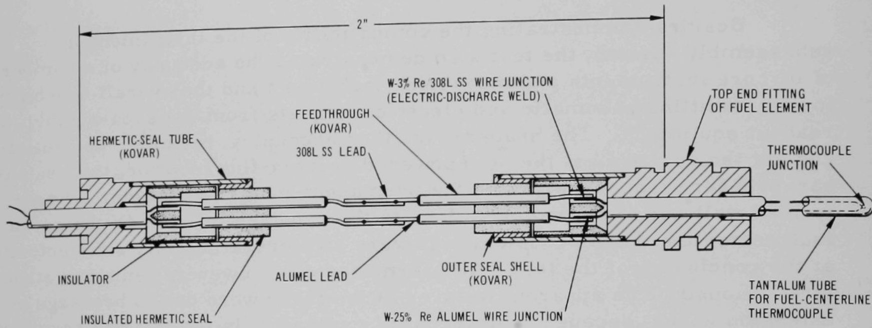


Fig. 33. Assembly of Fuel-centerline Thermocouple for Subassembly XX01

The hot junction was formed by tying the 0.010-in.-dia thermoelement wires (W-3% Re/W-25% Re) together with a 0.003-in.-dia W-3% Re wire and then capacitor-discharge-welding the thermoelement wires together below the W-3% Re wire wrap. This junction is much more rugged than a simple welded junction. Two-hole thoria beads were used to insulate the thermoelements both above and below the hot junction. A tantalum sheath, closed at the hot-junction end by an electron-beam weld, encased the thoria beads and the thermoelement wires. The sheath was filled with ultrapure helium. This type of construction was tested successfully out-of-pile at 1980°C for 260 hr.[7] Tests of the compatibility of tantalum and uranium oxide (the fuel in XX01) demonstrated that these materials were compatible at 2400°F for at least 63 hr.[8]

The tantalum sheath was brazed to the Type 304 stainless steel top end fitting of the fuel element with a pure copper braze material. Tests had shown that this braze joint could endure the expected thermal cycling. The end fitting was TIG-welded to the Kovar tube that formed the outer shell of the hermetic seal.

Two identical hermetic seals in series were used to form a double barrier to any fission gases that might be in the thermocouple. This type of seal was pretested and found to be leaktight at 1150°F with a 200-psi differential pressure. The W-3% Re/W-25% Re thermoelement wires were capacitor-discharge-welded to Type 308L stainless steel/Alumel base-metal lead-wire pairs.[9] Each hermetic seal was electrically insulated with alumina, and had two inner feedthroughs and an outer shell of Kovar. The Type 308L stainless steel/Alumel lead wires were brazed into the Kovar feedthroughs using commercially available Nioro brazing alloy containing 82% gold and 18% nickel. This alloy was chosen because of its low melting point (960°C), ease of application in wire or sheet form, and good strength characteristics.

The Nioro braze of the hermetic seal attached to the top end fitting of the fuel element closed the thermocouple well. After this closure, the thermocouple was calibrated at 1000°C and installed in its fuel element.

The second hermetic seal, which was attached to a lead sheathed with Type 304 stainless steel, was fabricated in a similar manner. The lead was brazed to the seal with Coast Metal 60 alloy. Subsequently (see Appendix B), the wires protruding from the feedthroughs of one seal were joined to those protruding from the other seal by capacitor-discharge welding. The sheathed lead (0.062-in. OD) contained Type 308L stainless steel/Alumel wires within crushed-alumina insulation. It was purchased to the high-quality specifications used for the coolant thermocouples.

When the hermetic seal attached to the top end fitting of the fuel element was being assembled, difficulty was encountered in brazing the Type 308L stainless steel wire to the feedthroughs in the helium atmosphere used in the tantalum sheath. This problem was solved by first brazing the Type 308L wire in a reducing atmosphere of dry hydrogen. The Alumel wire was brazed in the helium atmosphere, which was inserted after the assembly had been hydrogen-cleaned and evacuated. The helium remained within the closed assembly.

2. Coolant Thermocouples

The 14 coolant-type (outlet-coolant, inlet-coolant, and spacer-wire) thermocouples in subassembly XX01 were Chromel/Alumel units obtained from commercial sources, who made them to meet ANL specifications and quality-assurance requirements. Rigid quality-assurance procedures, which included in-plant inspections and approval of all material certifications, were required to obtain the desired product.

The combination of materials used in the construction of the coolant thermocouples was selected on the basis of results of ANL developmental programs. The sheath material was drawn from high-quality Type 304 stainless steel tube, the insulator was highly compacted and very pure (99.6% or better) crushed alumina, and the Chromel/Alumel thermoelements were of the highest grade available.

The coolant thermocouples (see Fig. 34) with the simplest geometry had a constant 0.062 in. diameter and varying lengths. The thermocouples of this type were: (1) the outlet-coolant thermocouple on capsule 5 (OTC 5); (2) the inlet-coolant thermocouple on the conduit located in position 4 (ITC 4); (3) the structural-material thermocouples in capsules 8 and 19 (STR 8 and 19); and (5) the thermocouples used as probes of the pressure sensors in capsules 11, 12, 16, and 18 (PSTC 11, 12, 16, and 18). STR 8 and ITC 4 are shown in Fig. 22, where ITC 4 is the smallest-diameter lead coming out of the conduit.

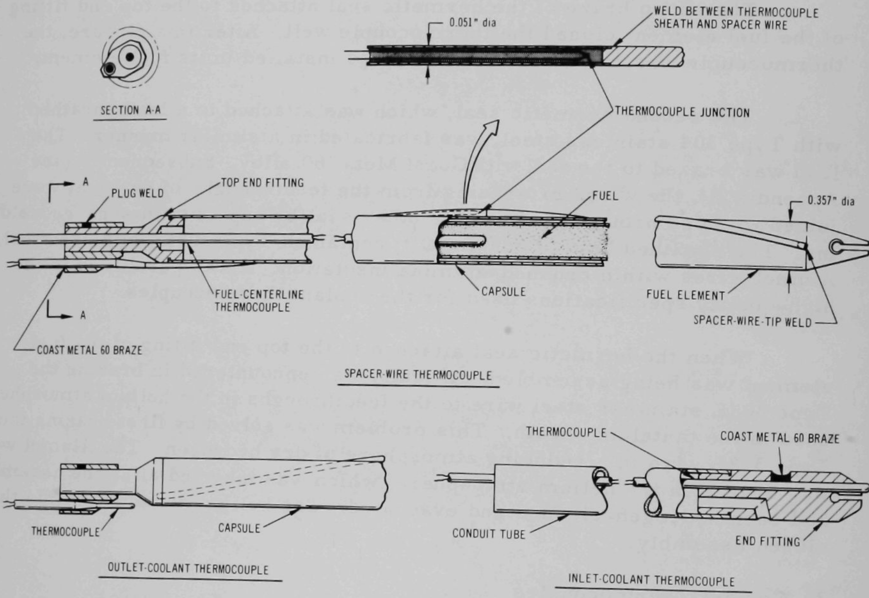


Fig. 34. Methods of Attaching Coolant Thermocouples for Subassembly XX01

The outlet-coolant thermocouples on capsules 6 and 14 (OTC 6 and 14) were of dual-diameter construction, with a 0.040 in. diameter at the hot junction (for a length of 1/4 in.) and a 0.062 in. diameter above the hot-junction region. Figure 22 shows the placement of OTC 14 at the top of the subassembly.

The four spacer-wire thermocouples were also of dual-diameter construction. They replaced spacer wires and were spiraled onto capsules 3, 7, 10, and 17 (and are identified as SWTC 3, 7, 10, and 17), which also contained fuel-centerline thermocouples. The upper attachment of SWTC 17 is shown in Fig. 22. The lead of the spacer-wire thermocouple was 0.062 in. in diameter, and the sensing portion, which spiraled around the capsule, was

0.040 in. in diameter. The sensing portion extended nearly to the axial core centerline. Below this level, the 0.040 in. diameter was continued with a Type 304 stainless steel wire.

3. Out-of-pile Tests

Eight sheathed Chromel/Alumel thermocouples (two spacer-wire, three outlet-coolant, one structural-material, and two inlet-coolant thermocouples) and one sheathed fuel-centerline thermocouple lead-wire pair (tested as a thermocouple) were successfully tested out-of-pile. These thermocouples were selected from the lot purchased for instrumented subassemblies and represented each type of stainless steel-sheathed thermocouple and lead wire in subassembly XX01. During the out-of-pile tests, the sensors were thermally cycled between two simulated EBR-II temperature distributions, with maximum temperatures of 700 and 900°F. Temperature changes were not rapid; an excursion between two temperature distributions took about one hour. Forty-eight temperature excursions were performed in three months. During this period, the measured loop resistance, insulation resistance, and voltage output of each thermocouple remained constant.

This out-of-pile test revealed no gross defect in the stainless steel-clad thermocouples; it also demonstrated the reliability of a relatively new thermocouple construction, i.e., the dual-diameter (0.062 to 0.040 in. OD) thermocouple that is spiraled and simultaneously serves as a 0.040-in.-OD capsule spacer wire.

APPENDIX B

Assembling Elements and Capsules for Subassembly XX01

1. Fuel

The fuel used in subassembly XX01 was uranium oxide nominally enriched to 44.5 wt % ^{235}U and in the form of cylindrical pellets. The pellets were produced by cold compaction of uranium oxide powder in steel tooling, followed by sintering at 1750°C in flowing hydrogen. The pellets were used as-sintered without any additional sizing or grinding. Some cylindrical pellets with holes through their centers (annular pellets) were produced to allow placement of the fuel-centerline thermocouple in some of the capsules. The outside diameter of all pellets was 0.246-0.247 in. Chemical requirements for the fuel were:

Enrichment	44.5 ± 0.1 wt % ^{235}U
Percent of theoretical density	95 ± 2%
Oxide/uranium ratio	1.99-2.01
Carbon content	130 ppm max
Total uranium content	88.04-88.14 wt %

Typical solid pellets stacked into a 14.2-in.-long column containing 102.6 g of total uranium, 56.5 g of ^{238}U, and 45.7 g of ^{235}U. In the 0.250-in.-ID stainless steel element tube, the smear density of the fuel was of the order of 93%.

Before the pellets were loaded into the element tubes, they were vacuum out-gassed at 1000°C for 1 hr in a furnace. After cooldown, the furnace was backfilled with helium. The out-gassed pellets were stored in helium at 1 atm until they were loaded into the element tubes. The gas content of the vacuum out-gassed pellets was determined by vacuum extraction of three samples at 1550°C. No significant release of gas was measured.

2. Capsules

Four types of instrumented capsules were produced, each characterized according to its instrumentation. These were capsules for: (1) spacer-wire thermocouples, (2) sodium-outlet thermocouples, (3) fuel-centerline thermocouples, and (4) fuel-element-pressure sensors.

Manufacture of the capsules for spacer-wire thermocouples and sodium-outlet thermocouples did not present any unusual requirements or development challenges. The capsules for the fuel-centerline thermocouples and the pressure sensors, however, presented considerable challenge and, therefore, are discussed here in detail.

a. Capsules for Fuel-centerline Thermocouples

Figure 35 shows the fuel-element assembly that contained the fuel-centerline thermocouple.* The instructions for the sequence of operations for fabricating this assembly read as follows:

(1) Clean fuel-element tube, spring, spring retainers, bottom end fitting, and thermocouple assembly.

(2) Assemble spring and spring retainers through bottom end of fuel-element tube.

(3) Insert top depleted-UO_2 annular pellet.

(4) Insert required length of enriched annular and solid UO_2 pellets.

(5) Insert bottom depleted-UO_2 pellet.

(6) Wipe tube end clean of UO_2 dust.

(7) Insert bottom end fitting.

(8) TIG-weld bottom end closure in place.

(9) Inspect weld by helium-sensitive mass spectrometer and by radiography.

(10) Insert thermocouple assembly through top end of fuel-element tube.

(11) In controlled-atmosphere welding chamber, TIG-weld top (final) closure of fuel section of element in 1 atm of helium gas.**

(12) Inspect weld (as in item 9).

(13) Clean parts associated with thermocouple splice chamber and the sheathed leads.

(14) Connect leads by spot-welding with capacitor-discharge resistance spot welder.

(15) Slip splice-chamber tube over the thermocouple assembly, and TIG-weld it to element end fitting.

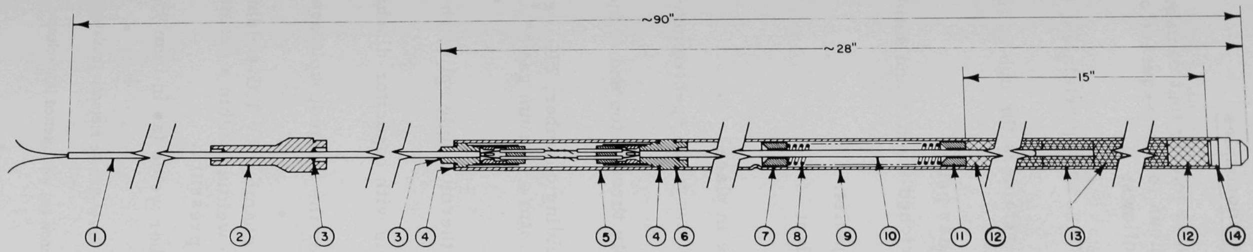
(16) Make final closure of splice chamber by TIG-welding splice-chamber tube to thermocouple assembly. Do welding within a gas mixture of 70% helium and 30% argon at atmospheric pressure.

(17) Inspect the two splice-chamber welds (as in item 9).

---

*The fuel-centerline thermocouples were tantalum-clad, W-3% Re/W-25% Re elements insulated with high-fired, high-purity thoria beads.

**Immediately before this weld was made, a small amount of xenon tag was inserted into selected elements (see Sec. 2.c of this appendix).



(1) SHEATHED LEADS

(2) TOP END FITTING OF CAPSULE

(3) BRAZE WITH COAST METAL 60

(4) TIG WELD

(5) SPLICE-CHAMBER TUBE

(6) TIG WELD - TOP CLOSURE OF ELEMENT

(7) SPRING RETAINER

(8) SPRING

(9) FUEL-ELEMENT TUBE

(10) TANTALUM THERMOCOUPLE TUBE

(11) FUEL RETAINER

(12) DEPLETED-UO_2 PELLET

(13) ENRICHED-UO_2 PELLETS

(14) TIG WELD - BOTTOM CLOSURE OF ELEMENT

Fig. 35. Fuel-element Assembly for Capsules Containing Fuel-centerline Thermocouples in Subassembly XX01. ANL Neg. No. 104-129 Rev. 1.

(18) Slide top end fitting of capsule into position over sheathed lead.

(19) Induction-braze top end fitting of capsule to sheath of lead with Coast Metal 60 braze alloy.

(20) Inspect braze joint visually and by helium-sensitive mass spectrometer.

The fuel-element assembly was then ready for insertion into the capsule. A sodium bond of high quality was required between the fuel-element assembly and the capsule. This bond was produced by a new procedure. The empty capsule was put into a drybox equipped with a vacuum apparatus. The capsule was evacuated, and a measured quantity of sodium was put into it. Then, the fuel-element assembly was slowly lowered into position, thus causing the sodium level to rise to a predetermined height. Inert gas was then bled into the capsule until its internal pressure rose to atmospheric. Bonding was then accomplished by heating the capsule to 930°F and holding at temperature for 2 hr. After the assembly had been bonded, it was cooled to 260°F and inspected for sodium level and bond by pulsed-eddy-current inspection.

After cooling to room temperature, the capsule was ready for the final closure weld. This weld was made in an atmospheric pressure in a controlled-vacuum/atmosphere welding chamber in gas containing 70% helium and 30% argon.

Finally, the spirally wound spacer wire was attached to the capsule by TIG-welding.

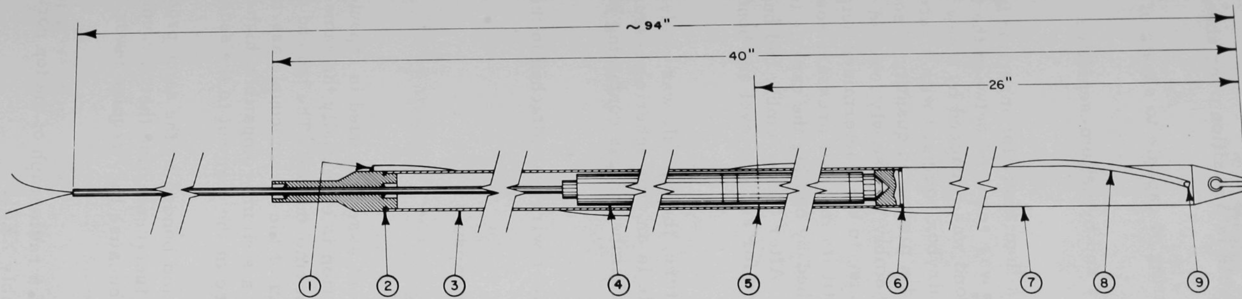
Figure 36 shows the completed capsule.

b. <u>Capsules for Pressure Sensors</u>

Figure 37 shows the fuel-element assembly used in capsules containing pressure sensors. The fuel portion is essentially the same as that of the elements with fuel-centerline thermocouples. The top end fitting, however, contains the pressure tube instead of the thermocouple assembly. The tube, brazed to the top end fitting with a sodium-compatible, high-nickel braze alloy, transmits the internal pressure in the element to the sensor.

The capsules were assembled and bonded by the same procedures used for the capsules containing the fuel-centerline thermocouples. However, they were simpler to assemble, because they require fewer assembling steps (see Fig. 38).

Figure 39 is a positive print of a radiograph of the top portions of the 19 completed capsules for subassembly XX01.



(1) TIG WELD OF SPACER WIRE TO TOP END FITTING

(2) TIG WELD OF TOP END FITTING TO CAPSULE TUBE

(3) CAPSULE TUBE

(4) FUEL-ELEMENT ASSEMBLY

(5) BOND-SODIUM LEVEL

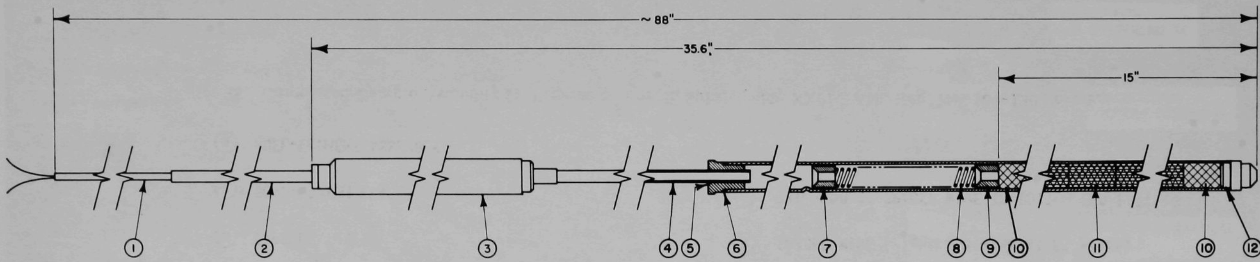
(6) TIG WELD OF BOTTOM END FITTING TO CAPSULE

(7) BOTTOM END FITTING

(8) SPACER WIRE (righthand wrap at 6" pitch)

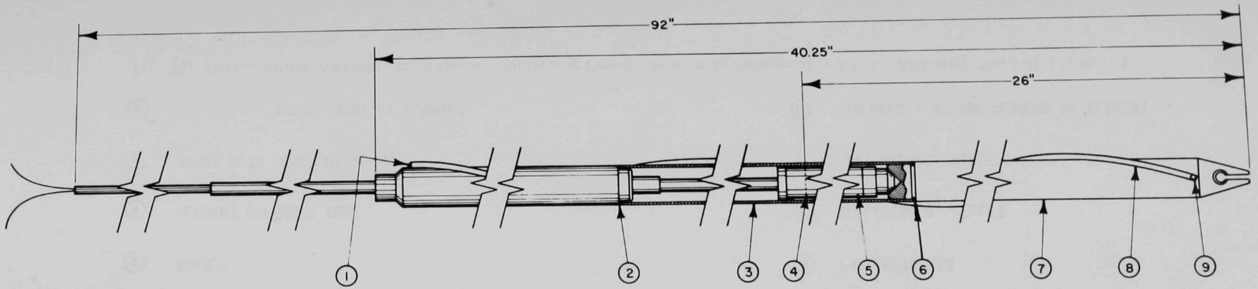
(9) TIG WELD OF SPACER WIRE TO BOTTOM END FITTING

Fig. 36. Completed Capsule Assembly for Fuel-centerline Thermocouple in Subassembly XX01. ANL Neg. No. 104-132 Rev. 1.



1	PROBE LEAD (0.062"-dia SS-sheathed chromel-alumel thermocouple)	7	SPRING RETAINER
2	REFERENCE-GAS PRESSURE TUBE	8	SPRING
3	SENSOR	9	FUEL RETAINER
4	ELEMENT PRESSURE TUBE	10	DEPLETED-UO_2 PELLET
5	BRAZE WITH COAST METAL 60	11	ENRICHED-UO_2 PELLETS
6	TIG WELD - TOP CLOSURE OF ELEMENT	12	TIG WELD - BOTTOM CLOSURE OF ELEMENT

Fig. 37. Fuel-element Assembly for Capsules Containing Pressure Sensors in Subassembly XX01. ANL Neg. No. 104-131 Rev. 1.



(1) TIG WELD OF SPACER WIRE TO SENSOR BODY

(2) TIG WELD OF SENSOR BODY TO CAPSULE TUBE

(3) CAPSULE TUBE

(4) BOND-SODIUM LEVEL

(5) FUEL-ELEMENT ASSEMBLY

(6) TIG WELD OF BOTTOM END FITTING TO CAPSULE TUBE

(7) BOTTOM END FITTING

(8) SPACER WIRE (righthand wrap at 6" pitch)

(9) TIG WELD OF SPACER WIRE TO BOTTOM END FITTING

Fig. 38. Completed Capsule Assembly for Pressure Sensors in Subassembly XX01. ANL Neg. No. 104-130 Rev. 1.

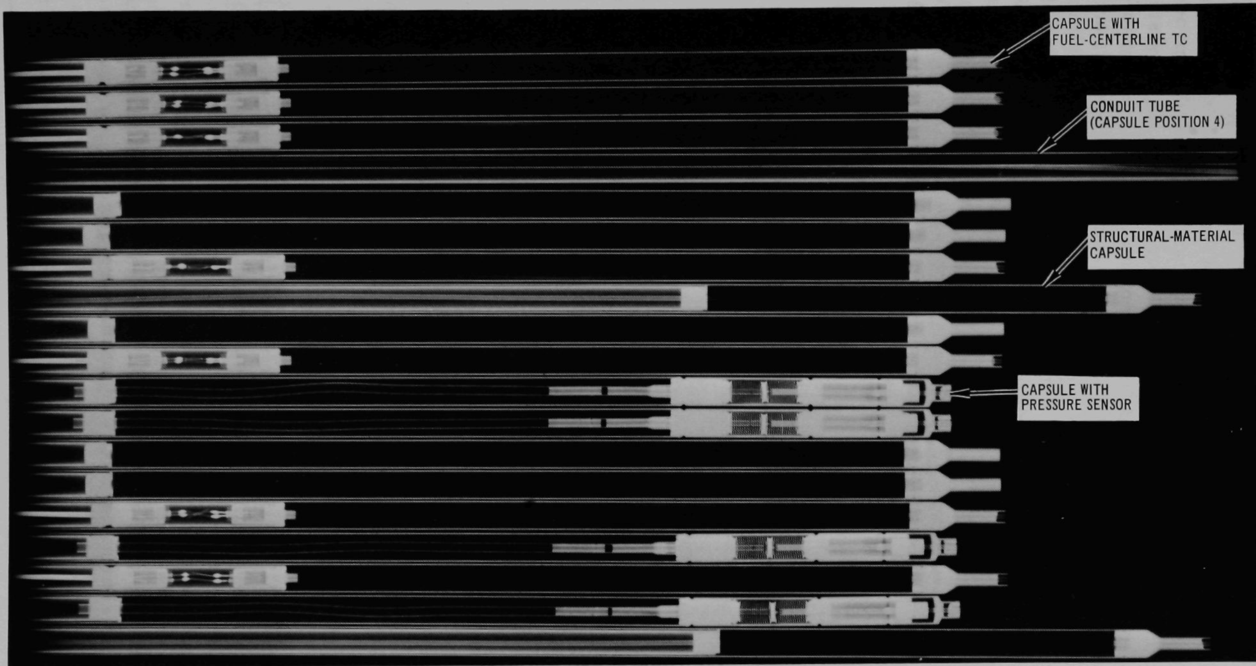


Fig. 39. Radiograph of Top Portion of Completed Capsules for Subassembly XX01

c. Welding Elements and Capsules

All end closures on the fuel elements and capsules were made by TIG-welding. Figure 40 shows the welding equipment used to produce the initial end closure of an element assembly or capsule. It consisted of a rectifier welding-power supply, a high-frequency arc starter, an automatic-weld-sequence programmer, a Visicorder weld-current recorder, and a glass lathe in which the parts to be welded were rotated. The welding torch was mounted on the lathe tool post and extended into a chamber that shrouded the parts being welded. During welding, a mixture of helium and argon gases flowing through the torch and the chamber provided an inert-gas environment (or cover) for the parts. Once the parts were positioned in the lathe, the weld sequence was automatically programmed through the following steps: (1) prepurge with inert gas; (2) start of arc; (3) welding; (4) weld termination (down slope); (5) postpurge with inert gas.

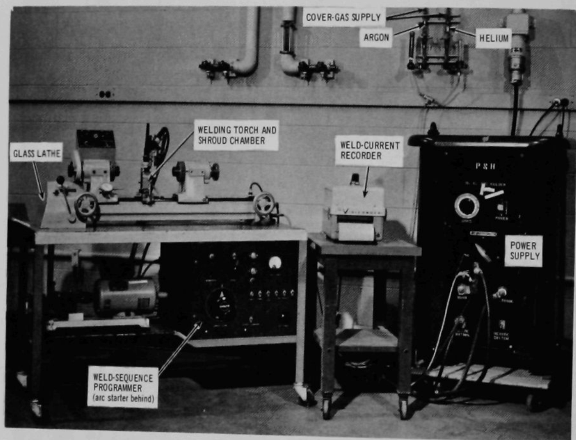


Fig. 40. Welding Equipment That Made Initial End Closures on Fuel-element Assemblies and Capsules for Subassembly XX01. ANL Neg. No. 104-134 Rev. 1.

The final end closures were made in a controlled-atmosphere welding chamber (see Fig. 41) capable of attaining high vacuum (5×10^{-5} Torr) as part of a purging cycle. Before the final closures were made, the fuel-element assemblies, or capsules, were placed in the welding chamber, and the chamber was evacuated and purged with ultrapure helium gas four times. The final weld closure was then made in helium at atmospheric pressure. One cubic centimeter of a unique mixture of xenon isotopes was added as a tag to the helium for each of several fuel elements.[10]

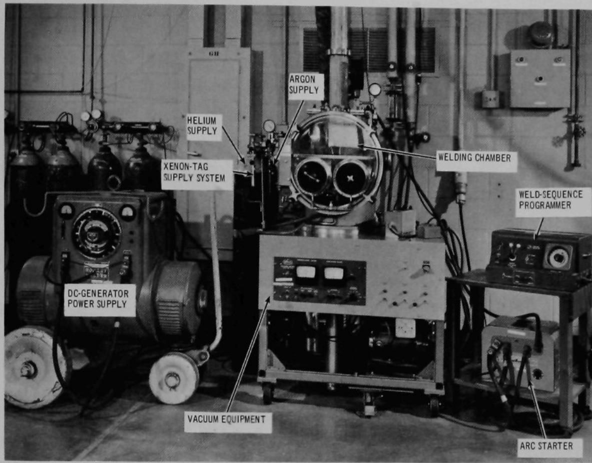


Fig. 41. Welding Equipment That Made Final End Closures on Fuel-element Assemblies and Capsules for Subassembly XX01. ANL Neg. No. 104-136A.

The purity of the helium atmosphere in the welding chamber was high. Gas samples taken from the welding chamber had the following typical volume-percent composition:

He	H_2O	N_2	O_2	CO_2
99.9	<0.1*	<0.02	<0.02	<0.02

d. Brazing

Two types of brazements were used in fabricating the fuel-element assemblies and capsules: (1) tantalum to stainless steel and (2) stainless steel to stainless steel.

(1) Tantalum/Stainless Steel Brazement. The 0.062-in.-OD x 8-mil-wall tantalum tube of the fuel-centerline thermocouple assemblies was copper-brazed in a vacuum to the stainless steel top end fitting of the fuel-element assemblies.

Figure 42 shows the metallurgical structure of the bond produced between the stainless steel and the tantalum. Since copper and tantalum have very limited metallurgical interaction, the bond zone does not become brittle. Samples of braze joints were checked for their integrity by thermal-cycling them 224 times from 790 to 1190°F. No leaks were detected with a helium-sensitive mass spectrometer.

*< indicates that concentration was below limits of detection.

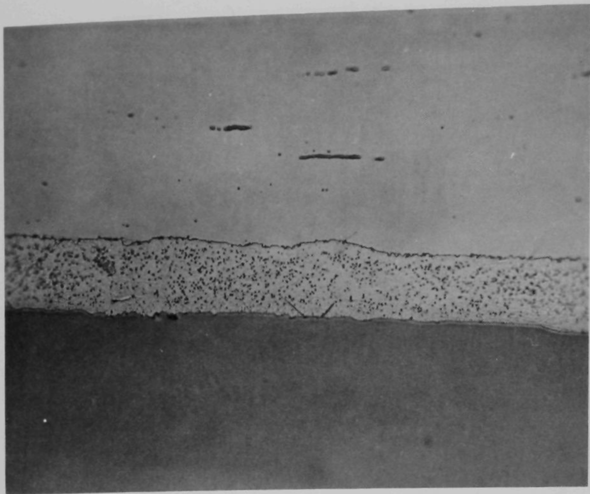


Fig. 42. Braze of Top End Fitting to Thermocouple Tube: Subassembly XX01

(2) Stainless Steel/Stainless Steel Brazement. The 0.062-in.-dia stainless steel-sheathed thermocouple leads of the fuel-centerline thermocouples were brazed to the top end fittings of the fuel-element assemblies and of the capsules. The clearance for the braze joint was established at 0.5-1.5 mils. Brazing was done in a hydrogen atmosphere, using induction heating. The braze material was the high-nickel alloy Coast Metal 60.

The brazed joints were examined visually and inspected for leaktightness with a helium-sensitive mass spectrometer.

APPENDIX C

Condensed Procedure for Bulkhead Brazing in Subassembly XX01

(NOTE: This is a condensed version of the authorized procedure as written. For simplification, drawings and other information in the authorized procedure are omitted.)

All materials are stainless steel and will be brazed with a high-nickel, high-temperature, sodium-compatible braze alloy (Coast Metal 60).

1. Attach two Chromel/Alumel thermocouples to the top surface of the bulkhead 180° apart. Resistance-spot-weld the TC hot junctions to the bulkhead.

2. Place another Chromel/Alumel thermocouple inside the 3/16-in.-dia tube from the conduit capsule, and adjust the hot junction to be in the center of the length of the braze joint.

3. Load the full subassembly into the brazing furnace.

4. Connect the three thermocouples to temperature recorders.

5. Position the bulkhead in the center of the induction coil. The vertical position is obtained automatically by setting the assembly on a stop on the furnace bottom.

6. Purge the chamber of air by pumping and backfilling with argon as indicated:

   a. Evacuate to 5×10^{-4} Torr.

   b. Backfill to 1 atm with argon.

   c. Evacuate to 5×10^{-4} Torr.

   d. Backfill to 1 atm with argon.

   e. Evacuate to 5×10^{-4} Torr.

   f. Backfill to 1 atm with argon.

   g. Evacuate to 6×10^{-5} Torr.

7. Fill chamber with hydrogen atmosphere as follows:

   a. Backfill to 5 in. water-gauge pressure with high-purity hydrogen.

   b. Establish a flow rate of 4-5 liters/min hydrogen, and ignite hydrogen overflow.

8. Perform hydrogen preclean of braze joint (no braze alloy) as follows:

a. Raise temperature to 2012°F in 35 min.

b. Hold at 2012°F for 10 min.

c. Raise temperature to 2156°F.

d. Hold at 2156°F for 3 min.

e. Cut power and allow furnace to cool in the hydrogen atmosphere.

9. When cool, replace hydrogen atmosphere with argon.

10. Open chamber, and introduce Coast Metal 60 braze alloy to bulkhead braze joint.

11. Close chamber, and repeat steps 5-9.

12. Open chamber, and remove brazed subassembly.

13. Install subassembly in leak-detection fixture.

14. Leak-detect using a helium-sensitive mass spectrometer.

APPENDIX D

Procedure for Wiring Drywell and Terminal Box of Subassembly XX01

1. Wiring the Drywell

In the drywell annulus, the wires (10-mil) of each sheathed lead were connected to the wires (20-mil) of a flexible lead in a splice region extending from 20 to 36 in. above the bulkhead.

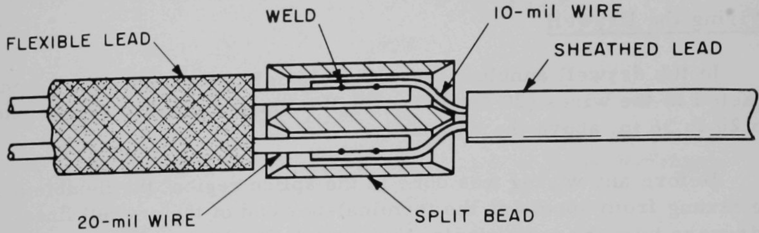
Before any wiring was done in the splice region, the flexible leads were strung from spools at the terminal-box end of the drywell liner. Leads were brought down singly, tied loosely in place against the drywell liner, and cut with ample excess length. The lead-wire pairs were twisted together at the terminal-box end, and each lead was tagged for identification. At the splice region, the loop resistances of the flexible lead and the sheathed extension lead were then measured and recorded.

In preparation for splicing, the sheathed leads were cut back at least 3 in. (to remove the section of the lead most likely to have absorbed moisture), but as much as necessary to avoid interference of its splice with other splices to be made. A stripping tool was used to remove 1/2 in. of sheath. The wires of the sheathed lead were scraped clean of alumina particles. Then, the alumina around the wires inside the sheath was removed to allow a 0.042-in.-OD insulator (with two 0.012-in. holes) to be inserted into the sheath to a depth of slightly more than 1/16 in. The 10-mil wires were straightened by stretching them slightly. The insulator was cut into 3/16 in. lengths and installed in the sheath, with the two wires going through the holes of insulator. Then, the loop and insulation resistances of the sheathed lead were measured.

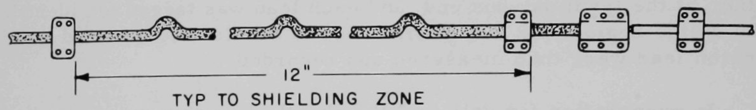
The insulation of the flexible lead was then trimmed for splicing. The material (Chromel or Alumel) of the leads was identified using a magnet or a polarity-indicating millivoltmeter.

The 10-mil wires of the sheathed leads were welded to the 20-mil wires of the flexible leads with a capacitor-discharge welder set at 18 W-sec. The welding electrode was pressed to the 10-mil wire, which was placed over the 20-mil wire. A pressure switch on the electrode caused the welder to discharge when the contact pressure reached 3 lb. After the weld was examined and found acceptable, a second weld was made as a backup (see A in Fig. 43).

One split-bead (0.128 in. OD) insulator was placed under the spliced wires and another on top, with the splices nesting well in the grooves of the beads. Then, a band of Type 304 stainless steel (0.005 in. thick, 0.25 in. wide) was firmly clamped over the split beads and spot-welded to the drywell liner (see B in Fig. 43). The capacitor-discharge welder was set at 50 W-sec, and the welder discharged when the contact pressure of the electrode reached 9 lb.



A. WIRE CONNECTIONS IN DRYWELL



B. TYPICAL BANDING OF LEAD WIRES IN DRYWELL

Fig. 43. Typical Wiring in Drywell of Subassembly XX01

The insulation resistance and the loop resistance of the wires were then measured with a Wheatstone bridge. This was done to detect possible discrepancies before proceeding further. Next, a strap was placed around the sheathed lead and also around the flexible lead near the splice. Then, three more straps were placed around the flexible lead with an expansion loop between each strap (see B in Fig. 43). The expansion loops were formed over a 0.1-in.-dia rod.

The flowmeter leads were spliced similarly, except that a larger insulator (0.0775 in. OD with two 0.025-in. holes) was inserted in the sheathed lead.

Three flexible leads with two Type 304 stainless steel wires were attached to the drywell liner to serve as sodium-level sensors. The ends of each lead, which terminated above the bulkhead, were inserted halfway into an 0.077 in. OD bead with 0.025-in. holes. The beads and the leads were strapped the same way as the flexible leads for the thermocouples.

Above the splice area, the strapping was applied every 12 in. over a number of adjacent leads, with three expansion loops between each strap. This was done on both sides of the drywell liner, except that, in the cooler shot-retaining region, the expansion loops were omitted. Finally, the leads were cut to manageable lengths, and their loop and insulation resistances were measured and recorded.

2. Wiring the Terminal Box

After the terminal box was bolted to the extension tube, the flexible leads were dressed, cut off, and connected to the terminal strips inside the box. After the leads were connected, but before the front and side covers were attached to the terminal box, loop and insulation resistances were checked at the terminal strips.

The hermetic-sealed connectors which had been attached previously to the front cover of the terminal box were prewired as follows: The connector pins and wires were scraped clean and then welded together. The welding was done by a special hand tool containing two insulated electrodes that could be placed under pressure around the pin and wire by squeezing the tool. The discharge power used to make this weld was 30 W-sec. Two welds were made for each wire and pin. Before the welds were made, a piece of insulating plastic tubing was slipped over each wire. This tubing was later slipped over the welded joint and pin. The ends of the lead wires welded to the connectors were tagged. Then, after the front cover of the terminal box, of which the connectors were a part, was attached to the terminal box, the tagged ends of the wires were connected to the terminal strip within the terminal box. This completed the wiring. Then, a final check of the loop and insulation resistances was made at the connectors on the terminal box and also through the mating connectors.

APPENDIX E

Tests of XX01 Instrumentation

A number of standard tests for the thermocouples, flowmeter, and pressure transducers were developed for use during the assembling and final checkout of the instrumented subassembly. The condensed procedures for the tests are given in this appendix.

1. Precision Tests of Thermocouples

a. Measure and record the electrical loop resistance of the wire pair of the thermocouple. Use a Wheatstone bridge capable of measuring resistance between 1 ohm and 10,000 ohms with an accuracy of ±0.1% of the reading.

b. Measure and record the wire-to-sheath insulation resistance of the thermocouple leads. Use a megohmmeter capable of measuring resistance between 10^{-1} and 10^{5} megohms with an accuracy of ±10%. Use a 50-V dc test voltage for all measurements taken out-of-reactor and less than 10 V dc for in-reactor measurements. NOTE: After a certain stage in assembling, when the thermocouple sheaths will no longer be accessible, measure the wire-to-structure resistance in lieu of wire-to-sheath resistance.

c. Verify that measured resistance values are within definite limits as indicated below:

(1) During Assembling. Loop resistances shall be within ±2% of the expected values previously measured and corrected for any removal or addition of thermocouple wire and insulation. Wire-to-sheath resistances shall be no less than 50% of expected values.

(2) After Assembling. Expected loop and wire-to-assembly resistances (at the terminal box) have been computed for out-of-reactor tests (68°F) and in-reactor tests (700°F) and are listed in Sec. 6 of this appendix. Record any loop resistance that differs ±10% from the values given in Sec. 6 or a low wire-to-assembly resistance.

d. Verify that measuring equipment is calibrated. Enter record of all calibrations on the data sheets.

2. Quick Tests of Thermocouples

a. Measure and record the electrical loop resistance of the wire pair of the thermocouple. Use a standard meter (e.g., Simpson 260) capable of measuring resistances between 1 ohm and 10,000 ohms to within ±10%.

b. Measure and record the wire-to-sheath (wire-to-subassembly) resistance of the thermocouple leads. Use a standard meter (e.g., Simpson 260) with an R X 10k range, greater than 10 ohms at center scale, and with a test voltage less than 10 V dc.

c. Immediately before and after use, check the meter calibration, on the ranges used, with known resistances of 100 ohms and 500k ohms.

d. Verify that measured resistance values are within definite limits as indicated below:

(1) <u>During Assembling</u>. Loop resistances shall be within ±10% of the expected values. Wire-to-sheath resistances shall be high enough to cause no deflection on the highest range of the meter.

(2) <u>After Assembling</u>. Expected loop and wire-to-assembly resistances are listed in Sec. 6 of this appendix for out-of-reactor (68°F) and in-reactor (700°F) tests. Record any loop resistance that differs ±20% from the values given in Sec. 6 or a wire-to-sheath resistance that is less than 50% of the expected value.

3. <u>Tests of Flowmeter Resistance</u>

Measure and record the loop resistance of the wire pair of the flowmeter with a Wheatstone bridge having an accuracy of ±0.1% of the reading. Record any loop resistances exceeding ±0.1% of the expected values. Make measurement after the flowmeter has been in the room for at least 8 hr at ambient temperature.

4. <u>Measurement of Flowmeter Fringe Flux</u>

a. Before assembling the subassembly:

(1) While facing the outlet end of the flowmeter, locate the hexagonal face of the flowmeter (Face 3A) that is adjacent to the sheathed lead. On this face, make a temporary transverse mark $4\frac{11}{16}$ in. from the inlet end of the flowmeter. This face is adjacent to the north pole piece, and the mark will be on the magnetic-pole centerline for subassembly XX01.

(2) Make a corresponding mark on the diametrically opposite face of the flowmeter. This face is adjacent to the south pole piece.

(3) Using the Hall probe gaussmeter, measure and record the magnetic-flux density at the longitudinal marks determined in steps (1) and (2) above. To do this, remove the probe shield and move the flat side of the active section of the probe lightly against the face of the flowmeter until a minimum reading is obtained. The values so measured should duplicate those previously determined.

b. After welding the flowmeter in the grid tube of the subassembly:

(1) While facing the inlet end of the flowmeter, locate the face of the grid tube that is 150° counterclockwise from the subassembly identification mark. On this face, make a temporary transverse mark $4\frac{31}{32}$ in. from the inlet end of the grid tube. This face is adjacent to the north pole piece, and the mark will be on the magnetic-pole centerline for subassembly XX01.

(2) Make a corresponding mark on the diametrically opposite face of the grid tube. This face is adjacent to the south pole piece.

(3) Measure and record the magnetic-flux density at these points in accordance with step 4.a(3).

c. After welding the grid tube to the lower adapter of the subassembly, repeat and record the flux measurement called for in step 4.a(3).

d. After slipping the hexagonal tube over the grid tube containing the flowmeter:

(1) While facing the inlet end of the flowmeter, locate the face of the hexagonal tube as in step 4.b(1). On this face, etch a permanent transverse mark $10\frac{31}{32}$ in. from the bottom of the hexagonal tube. This face is adjacent to the north pole piece, and the mark will be on the magnetic-pole centerline.

(2) Make a corresponding mark on the diametrically opposite face of the hexagonal tube. This face is adjacent to the south pole piece.

(3) Measure and record the magnetic-flux density at these points in accordance with step 4.a(3).

e. After each subsequent welding operation on the subassembly and extension tube, perform measurements in accordance with step 4.a(3) at the marks determined in steps 4.d(1) and 4.d(2).

5. <u>Test of Pressure Transducer</u>

a. Alternately apply a vacuum of 3 psig and a pressure of 3 psig to the reference-gas side of the pressure transducer. Use argon gas. Record the pressure (or vacuum) at which the transducer probe makes or breaks contact. Connect standard meter (e.g., Simpson 260) between the gas tube and both thermocouple wires of the transducer probe. Breaking contact shall be a resistance reading greater than 1000 ohms, and making contact shall be a resistance reading less than 100 ohms.

b. Perform the thermocouple test of the transducer probe in accordance with the standard thermocouple tests (Sec. 1 or 2). Perform this test with 20 psig applied to the bellows to ensure that the thermocouple is ungrounded.

6. Expected Instrument Resistances

Table VII lists typical expected resistances of instruments of subassembly XX01, as measured at the terminal box.

TABLE VII. Expected Resistances[a] of Instruments of Subassembly XX01

Instrument	Loop Resistance, ohms		Wire-to-Assembly Resistance, ohms	
	68°F	700°F	68°F	700°F
Fuel-centerline thermocouple	~69	~96	$>100 \times 10^6$	$>10 \times 10^6$
Inlet-coolant thermocouple	~74	~99	$>100 \times 10^6$	$>10 \times 10^6$
Cladding thermocouple	~79	~107	$>50 \times 10^6$	$>5 \times 10^6$
Outlet-coolant thermocouple	~47	~61	$>100 \times 10^6$	$>10 \times 10^6$
Structural-material thermocouple	~65	~83	$>100 \times 10^6$	$>10 \times 10^6$
Flowmeter	~77	~106	~38	~53
Pressure-transducer probe	~52	~68	$>100 \times 10^6$	$>10 \times 10^6$

[a]As measured at terminal box.

APPENDIX F

Condensed Procedure for Installing Subassembly XX01

(NOTE: This is a condensed version of the authorized procedure as written. For simplification, reference drawings and other information in the authorized procedure are omitted.)

1. Installation of Subassembly

a. The instrumented subassembly is shipped in a specially designed shipping container that supports the subassembly in the horizontal position. Upon arrival of the shipping container at the EBR-II site, remove the cover plates and the inner container housing the subassembly. Do not remove the subassembly until the inner container is in the reactor building and raised to a vertical position. The inner container is supported in the vertical position on I-beams across the top surface of the storage pit.

b. Remove the cover plates and the container extension from the inner container.

c. Support the instrumented subassembly, using the eye nut at its top. Use a dynamometer to monitor the hoisting load. The hoisting load should not exceed 350 lb.

d. Remove the clamp supports that secure the instrumented subassembly to the inner container, starting with the lower clamp support and ending with the upper-flange support; this separates the subassembly from the container. The subassembly is now supported free of the container.

e. Remove the empty inner container. Handle the instrumented subassembly in the vertical position only, once separated from the inner container.

f. At this time, examine the instrumented subassembly to ascertain that it has been received at the EBR-II site in satisfactory condition. Perform tests in accordance with specific instructions listed in "Tests of XX01 Instrumentation."*

g. Remove the cover drive according to normal procedures.

h. Remove two horizontal support channels on the west side of the superstructure.

i. Raise the lead-screw/ball-nut housing to the full-up position and proceed as follows:

---

*See Appendix E of this report.

(1) Plug the instrumented-subassembly preheater into a 115-V ac plant electrical outlet. Connect the preheater to a portable temperature indicator. Purge the preheater cavity with argon, and then cover the opening at the top. Allow the preheater to heat up for 3 hr. The preheater temperature should read 650-750°F.

(2) While the preheater is heating up, remove the plastic bag from the lower part of the instrumented subassembly. Connect the "sodium heat-transfer thermocouple" pins (six thermocouples) of the connectors on the terminal box to the readout equipment.

(3) Insert the lower 8 ft of the instrumented subassembly into the preheater. Allow the subassembly to heat up in the preheater for 8 hr or until the "upper sodium heat-transfer thermocouple" readout is greater than 600°F.

(4) Remove the bolts holding the bellows blind flange to the top of the bellows assembly.

j. Caution: This step must be completed in less than 30 min to keep the sodium bond in the fuel capsules liquid. Transfer the instrumented subassembly from the preheater to the No. 6 control-rod-drive location. Orient its terminal box in the proper radial direction, remove the bellows blind flange, and lower the subassembly into the control-rod opening until the bellows top flange is 60 in. from the terminal-box lower flange.

k. Install the cover-gas seal plate on the top of the bellows assembly.

l. Hold the subassembly in a 60-in. position for 5 hr. Then remove the seal plate, and lower the subassembly the remaining distance. The subassembly will now be supported on the tapered seat of the control-rod-guide-thimble adapter.

m. Remove the Teflon sleeve from the outside of the bellows.

n. Disconnect the bellows top flange from the bellows support structure, and attach the bellows top flange to the terminal-box lower flange.

o. Install the bellows support structure in accordance with the following instructions:

(1) Measure the distance between the top surface of the lower plate and the underside surface of the bellows top flange (measurement A). Machine shim blocks to a thickness equal to measurement A less 0.812 in. Install these shim blocks onto the underside of the upper plate.

(2) Raise subassembly $1\frac{1}{2}$ in. Attach the assembly of the upper plate and shim blocks to the lower plate.

(3) Install the lower interlock yoke on the upper plate.

p. Lower the subassembly onto the bellows support structure. Disconnect the hoisting device from the eye nut at the top of the terminal box. Remove the eye nut from the top of the terminal box.

q. Install the elevator assembly to the lead-screw/ball-nut housing. Do not install the push-pull force switch and potentiometer and the load-cell transducer. Attach the guide plate and load-cell transducer to the connecting flange, and attach the connecting flange to the terminal box. Lower the elevator assembly, and attach it to the terminal box by inserting a pin in the connecting yoke.

r. Verify that the terminal-box pressure indicates 14 psig. Bleed or add argon gas if necessary.

s. Install the cover-drive motor according to normal procedures.

t. Install two horizontal support channels on the west side of the superstructure.

u. Raise the instrumented subassembly about 2 in.

v. Attach the electrical cables. Perform the following electrical checks:

(1) Energize the fuel-handling console, and enter pushbutton sequence A (which prepares the reactor for fuel handling).

(2) Operate the instrumented-subassembly-system limit switches, and note that the proper relays function in the fuel-handling console.

(3) Check that the lower interlock yoke is retracted, and raise the instrumented-subassembly elevator a short distance to test the "up" drive control.

(4) Similarly, test the "down" control.

(5) Drive the instrumented subassembly to the full-down position. Adjust the lower-limit-of-travel switch so that power to the mechanism drive is cut off at an elevation that will permit the lower interlock yoke to engage the square cutout located under the bellows top flange.

(6) Raise the instrumented subassembly a short distance, simulate the occurrence of a push (and pull) force beyond the set limit, and test that it prevents down (and up) motion of the instrumented-subassembly drive.

(7) Attempt to initiate platform motion in pushbutton sequence A without driving the instrumented subassembly to the up position.

(8) Raise the instrumented subassembly to the full-up position (96 in. from the full-down position). Adjust the upper-limit-of-travel switch so that the power to the mechanism drive is cut off at an elevation that will permit the upper interlock yoke to engage the spacer between the interlock support nut and the elevator support nut located at the top end of the elevator shaft.

(9) Perform a number of down and up operations to check the positions of the limit switches, ending with elevator in full-up position.

(10) Engage the upper interlock yoke, and check that the platform or the cover cannot be run. Retract the upper interlock yoke.

(11) Proceed with operations in sequence A (but do not melt seals), and perform the following tests:

(a) Whenever the platform moves up (and down), simulate a push (and pull) force beyond the set limit on the instrumented-subassembly force-detection mechanism, and check that the platform stops.

(b) Simulate a push force while the reactor cover is being raised, and observe that the cover stops. Record the settings.

(12) Check that the "close cover gland" step cannot be performed with the upper interlock yoke retracted.

(13) Engage the upper interlock yoke.

(14) Proceed in pushbutton sequence A with the step of disconnecting the cables while observing for any anomalous behavior of the fuel-handling system. Note that the "cables disconnect" indication occurs.

(15) Switch to sequence H of the fuel-handling console. Reconnect all cables (except instrument cables).

(16) Proceed to the step "lower cover," and note that the step cannot be performed with the upper interlock yoke engaged.

(17) Retract the upper interlock yoke.

(18) Check that downward motion of the instrumented subassembly cannot be initiated at this point.

(19) Proceed with the "lower cover" step; simulate a pull force on the instrumented-subassembly drive, and observe that it stops the reactor cover.

(20) Proceed with the platform motions; simulate a pull (and push) force whenever the platform is moving down (and up) and observe that the platform stops.

(21) Complete the platform motions in sequence H, and check that sequence H cannot be reset at this point.

(22) Lower the instrumented subassembly to its full-down position. Engage the lower interlock yoke.

(23) Reset sequence H and deenergize the fuel-handling console.

(24) Interrupt the instrumented-subassembly full-down circuit, and check that the "fuel handling complete" circuit is also interrupted.

w. Perform tests in accordance with "Tests of XX01 Instrumentation."*

2. Instrumented-subassembly Connections to Readout Equipment

a. Plug in the instrument-cable connectors, and connect the instrument tubing at the terminal box.

b. Purge the tubing and transducer controller with argon as follows:

(1) Disconnect the vent connection at the transducer controller.

(2) Connect a vacuum pump to the vent connection on the transducer controller.

(3) Turn on the transducer controller to open the solenoid valves.

(4) Start the vacuum pump.

(5) After the system has been pumped down to the limit of pump capability, shut off the pump and backfill the system with argon gas from the transducer-controller argon supply.

---

*See Appendix E of this report.

(6) Turn off the transducer controller, thereby shutting the solenoid valves.

(7) Disconnect and remove the vacuum pump.

(8) Connect the vent line to the transducer controller.

APPENDIX G

Condensed Procedure for Testing Subassembly XX01 before and during Reactor Startup

(NOTE: This is a condensed version of the authorized procedure as written. For simplification, reference drawings, tables, and other information in the authorized procedure are omitted.)

1. Purpose

a. Before reactor startup and with the primary bulk sodium at 700°F, to verify instrument-sensor performance at zero reactor power and with reactor-coolant flow rates varied between 25 and 100% of full flow.

b. To conduct performance tests of the instrumented-subassembly sensors and instrument systems during reactor startup and at 50-MWt reactor power level.

2. Instrumentation

Record data from the instrumented-subassembly sensors by four different systems as follows:

a. Strip-chart recorders in the instrumented-subassembly cubicle located in the control room.

b. Multiple-input data-acquisition system (MIDAS)--an analog-to-digital, magnetic-tape, data-logging system.

c. Postincident recall system (PIR).

d. A wide-band (0-10 kHz) recording system to be provided by ANL-Illinois.

3. Tests before Reactor Startup

a. Plant Conditions. Verify that the plant is at standby conditions with primary bulk sodium at 700°F and pumps operating to provide a minimum flow rate (25%).

b. Preparatory

(1) Verify that new charts have been installed on the 14 instrumented-subassembly strip-chart recorders in the control room, and that the pens are inking properly.

(2) Adjust the chart drives for 4-in./hr chart speed.

(3) Turn on the recorders, and observe that chart drives are operating.

(4) Mark the charts with recorder number, sensor number, date, and time to nearest minute.

(5) Start up the MIDAS, and set the scan rate at 10-min intervals.

(6) Install the wide-band (up to 10 kHz) recording system provided by ANL-Illinois in the reactor building, adjacent to the MV/I cubicle.

(7) Check out the wide-band recording system by providing simulated inputs to the six channels to be used for noise-signal measurements.

c. Sensor Tests

NOTE: The Test Engineer is responsible for accomplishing the tests defined by this procedure.

(1) Verify that the pumps are operating and the reactor-coolant flow rate is adjusted to minimum (25%).

NOTE: Mark the recorder charts with recorder number, sensor number, date, and time. Verify that the recorders are operating.

(2) Operate under the minimum primary-system flow-rate conditions for 10 min, recording instrumented-subassembly data on control-room strip-chart recorders.

(3) Verify the acceptability of the data and performance of the sensors.

d. Temporarily disconnect the following sensors from the MV/I transmitters, and connect them to the wide-band recording system:

Flowmeter (FM-4)
Outlet Thermocouple No. 5 (OTC 5)
Outlet Thermocouple No. 14 (OTC 14)
Inlet Thermocouple (ITC 4)
Cladding Thermocouple SWTC 17

e. Verify that signal inputs for the wide-band recording system are provided from EBR-II normal operating instrumentation as follows:

(1) Reactor-coolant total flow (EM flowmeter).

(2) Nuclear channel--Experimental as specified by Test Engineer.

NOTE: The EM flowmeter is connected to the reactor shutdown circuit.

f. Record data on sensor-noise signals for inputs connected to the wide-band recording equipment.

NOTE: Time for recording sensor-noise signals is estimated to be less than 1 hr.

g. Disconnect the sensor-input connections from the wide-band recording system, and reconnect them to the MV/I transmitters.

h. Verify that the strip-chart recorders in the instrumented-subassembly cubicle in the control room are turned on and operating with the chart speed at 4 in./hr.

(1) Verify that the PIR is operating.

(2) Mark the charts with date, time, sensor number, and recorder number.

i. Record data simultaneously on the strip-chart recorders, MIDAS, and PIR for not less than 10 min. Set the MIDAS scan rate at 1-min intervals. Verify that performance of sensors as recorded is correct and satisfactory.

NOTE: Mark the recorder charts with date, time to the nearest minute, sensor number, and recorder number.

j. Flow Tests

(1) With the reactor shut down, simultaneously record data for 10 min on the strip-chart recorders, MIDAS, and PIR at each of the specified reactor-coolant flow conditions. The MIDAS scan rate is to be at 1-min intervals, and recorder chart speed is to be 4 in./hr.

(2) Specified reactor-coolant flow conditions are 25, 50, 60, 70, 80, 90, and 100% of total flow. At the beginning and end of each flow test, mark the recorder charts with the date, time to nearest minute, sensor number, and recorder number.

4. Reactor-startup and Power-operation Tests

The test procedures for reactor startup and power operation are supplementary to the attached special operating procedure.

a. Preparatory

(1) Verify that the 14 strip-chart recorders have new charts, recorders are turned on, and chart speeds adjusted to 4 in./hr.

(2) Verify that the PIR is operating.

(3) Verify that the MIDAS is operating and that the scan rate is at 1-min intervals for reactor startup and at 10-min intervals for operation at power.

b. Tests during Reactor Startup

(1) Verify that plant conditions are in standby with bulk sodium at 700°F.

(2) Start up the reactor, and adjust the power level to 500 kW.

(3) Perform reactivity-coefficient determination by control-rod-drop technique.

(4) Adjust strip-chart speeds to 2 in./min (120 in./hr) and MIDAS scan rate to one scan per minute.

NOTE: Mark the recorder charts at the beginning and end of each test with date, time to nearest minute, sensor number, recorder number, and chart speed for each of the following tests:

(5) Increase reactor power to 10 MW. Hold the power at this level for 90 min. Continuous recording by the strip-chart recorders, MIDAS, and the PIR is required. Make noise-level measurements (steps 4.b(6)-4.b(9) concurrently with this test.

CAUTION: Temperatures as recorded during the wide-band noise measurements are to be closely monitored. If any temperature is observed to increase, verify the instrumented-subassembly flow rate by calling the Test Engineer.

NOTE: Mark the strip charts at the beginning of the test and 90 min later at the conclusion of the 90-min test.

(6) Disconnect the sensors from the MV/I transmitters as follows:

(Before disconnecting the sensors, verify that their output signal has been constant for 10 min.)

Flowmeter (FM-4)
Outlet Thermocouple No. 5 (OTC 5)
Outlet Thermocouple No. 14 (OTC 14)
Inlet Thermocouple (OTC 4)
Cladding Thermocouple SWTC 17

NOTE: Low-level alarms at the instrumented-subassembly-system annunciator will occur when the sensors are disconnected.

(7) Monitor thermocouple SWTC 10 readout closely on recorder No. 5 while thermocouple OTC 14 is disconnected from recorder No. 12 throughout the incremental power-level measurements.

(8) Connect these sensors to the wide-band recording system.

(9) A signal input for the wide-band recording system is to be provided from EBR-II normal operating instrumentation as follows:

(a) Reactor-coolant total flow (EM flowmeter).

(b) Nuclear channel--Experimental as specified by Test Engineer.

(10) Verify that reactor power level is stable for 30 min at 10 MW, and record wide-band sensor-noise measurements for 30 min. Run this test concurrently with step 4.b(5).

(11) Disconnect sensors from the wide-band recording system, and connect them to the MV/I transmitters.

(12) Increase the reactor power level in 5-MW increments. Repeat steps 4.b(5)-4.b(11) after each 5-MW incremental increase until the 50-MWt power level is achieved.

c. Tests during Reactor Operation

(1) After power-level incremental tests are completed and with the reactor at 50-MWt power level, perform reactivity-coefficient determinations by control-rod-drop technique.

(2) After the rod-drop test is completed, reduce recorder chart speeds to 4 in./hr and MIDAS scan rate to 10 min for recording data during the reactor run.

(3) With reactor power level at 50 MWt, continue the reactor power run in accordance with run-authorization instructions.

(4) Data are to be recorded continuously by the PIR.

APPENDIX H

Data-handling Checkout for Subassembly XX01

The data-handling and readout instrumentation for subassembly XX01 was installed, checked out, and calibrated before starting the in-reactor test.

The MIDAS (Multiple-Input Data-Acquisition System) was already in the EBR-II plant; however, it was necessary to bring the signals to a patch panel and interconnect them to system input channels reserved for the signals from the subassembly. After this, the calibration of the MIDAS was verified.

The cabinet for the strip-chart recorders, which was built especially for the test, housed 14 strip-chart recorders; a panel of annunciators, alarms, and their related circuitry; a time-marker unit; fuses; and terminal boards for signal connections and power-supply connections. This cabinet was in the EBR-II plant control room and was not movable.

The cabinet for the MV/I transmitters, also made especially for the test, was like a typical relay rack mounted on wheels. It was located on the operating floor of the EBR-II reactor plant. All the electrical connections to it were flexible.

Since the instruments within the subassembly were inaccessible after the fabrication was completed, the tests and checks of the sensors were done by way of the multipin electrical connectors on the subassembly terminal box. (Certain tests and checks on the fission-gas-pressure transducers were done via the controller units for the transducers.)

The tests consisted of measuring loop resistances and insulation resistances for the 22 sensors in the subassembly. Magnetic flux at the north and south poles of the permanent-magnet flowmeter was measured before installation.

Testing of the fission-gas-pressure transducers and of their controller units was done via the controller units. The controller units and their gas bottles were placed into the test instrument room of the reactor about 10 days after the instrumented-subassembly system had been installed in EBR-II.

The data-transmission and readout equipment was checked out after it had been installed and interconnected. The sensor signals were simulated by applying equivalent millivolt-level signals to the inputs of the MV/I transmitters and measuring the outputs of the transmitters and the pen traces of the strip-chart recorders.

The MIDAS was interconnected to the sensor signals of the subassembly. The calibration check was made manually on the MIDAS channels, similarly to what was done for the recorders. A loading check was made for the thermocouple signals to ascertain that the thermocouples were not being loaded by the data-readout equipment.

APPENDIX I

Condensed Procedure for Operating Subassembly XX01 in EBR-II

(NOTE: This is a condensed version of the authorized procedure. For simplification, reference drawings and other information in the authorized procedure are omitted.)

1. General

a. The normal procedures provided in the Operating Manual are to be used for startup and operation of the reactor with the instrumented subassembly installed.

b. The instrument panel, located in the control room, contains 14 double-pen recorders for readout of all parameters associated with the instrumented subassembly. All alarms related to the instrumented subassembly are also annunciated on this panel.

c. An "interval marker," located on the instrument panel, provides for the periodic (preselected) marking of all charts simultaneously. A selector switch permits selection of the desired marking interval. An "event marker" pushbutton also permits the simultaneous marking of all charts, exclusive of the selected interval, whenever an incident occurs.

2. Startup

a. Verify that the 14 strip-chart recorders on the instrument panel have the chart drives turned on, have a new and proper chart installed, and that all pens are inking.

b. Mark all charts with the recorder or sensor number, the date, the time to the nearest minute, and the chart speed. Use the "event marker" to mark all charts simultaneously. Also mark each chart when the chart speed is changed.

c. Verify that chart speeds are set as specified by the Analysis and Test representative.

3. Abnormal Operation

The following operator action is required on receipt of alarms associated with the instrumented subassembly:

a. If simultaneous alarms are received on outlet-coolant high temperature (window 36, 41, or 43) and subassembly-coolant low flow (window 24), perform an anticipatory shutdown to 5 MWt and notify the Systems Engineer and the Operations Manager.

b. If simultaneous alarms are received on terminal-box low pressure (window 21) and sodium level (window 45, 46, or 47), perform an anticipatory shutdown of the reactor, secure the primary pumps, and notify the Operations Manager.

c. If a terminal-box low-pressure alarm is received (window 21), immediately check the local gauge at the terminal box. If the indicated pressure is 8 psig or less, perform an anticipatory shutdown of the reactor, secure the primary pumps, and notify the Systems Engineer. If the pressure is above 8 psig, the terminal box may be repressurized with argon without shutting down the reactor. (See item 3.f below for the refilling procedure.)

If the reactor and pumps were shut down, any leaks must be repaired and the terminal box repressurized before the primary pumps are restarted.

d. If any of the sodium-level probes alarm (window 45, 46, or 47), with no indication of a low terminal-box pressure, notify the Systems Engineer.

e. If a fission-gas-pressure (pressure-transducer) high or low alarm is received (window 26, 27, 28, 30, 31, 32, 33, or 37) accompanied by an "Instrumented Subassembly Radiation High" alarm (window 41 on the radiation-monitoring panel in the control room), isolate the transducer system from the instrument panel in the control room. Instruct the Health Physics technician to monitor the transducer lines where they enter the terminal box, and if the activity level permits, close the four manual isolation valves at the terminal box and the four manual valves by the transfer arm.

f. If at any time a terminal-box high- or low-pressure alarm is received (window 21 or 22), be sure the pressure is returned to within the normal range, either by adding argon or by bleeding excess argon to atmosphere. The reactor need not be shut down to perform this operation (unless required in item 3.c above). The normal pressure range is 10-14 psig, with the low alarm set at 10 psig and the high alarm at 15 psig.

A gas manifold, located at the top of the terminal box, provides for adding or bleeding argon. The manifold consists of:

A gauge to measure pressure,

Limit switches to cause an alarm on high or low pressure,

A safety relief valve set to open at 25 psig, and

A charging valve (normally closed and capped) with an orifice to limit flow rate.

(1) In the event of a low-pressure alarm, add argon as follows:

(a) Verify that the charging valve is closed, and remove the pipe cap from the valve.

(b) Attach an argon bottle to the charging valve. Either the bottle or the connecting line must have a pressure regulator set at no more than 20 psig.

(c) Crack open the charging valve, and allow argon to enter the terminal box. Closely observe the pressure gauge, and close the charging valve when the pressure reaches 12 psig.

(d) Disconnect the argon supply line, and reinstall the pipe cap on the charging valve.

(2) In the event of a high-pressure alarm, bleed argon to the atmosphere as follows:

(a) Verify that the charging valve is closed, and remove the pipe cap from the valve.

(b) Crack open the charging valve, and allow gas to escape. When the pressure gauge indicates 12 psig, close the charging valve.

(c) Install the pipe cap on the charging valve.

g. Whenever an alarm is received, press the "event marker" button and mark the appropriate recorder chart with the time and date and any information known at that time relating to the alarm. Also record this information in the console log.

APPENDIX J

Summary of Unrestricted-fuel-handling Procedures with the Instrumented Subassembly Installed

After a normal reactor run and immediately before "unrestricted fuel handling," certain reactor components are in specific positions. The control-rod drives are attached to the control rods, which are in the "down" position. The control-rod-drive lifting platform, at the "operate" elevation, is resting on the platform blocks on top of the small rotating plug. The reactor-vessel cover is "down" and locked. The platform locks are in place, thereby preventing any upward motion of the platform greater than about 1/8 in. The instrumented-subassembly drive is "down" and locked by the lower interlock yoke.

The sequence of operations involving the instrumented subassembly used during unrestricted fuel handling follows. These operations are controlled at the fuel-handling console and are part of the sequence labeled "sequence A."

1. Sequence A is selected, and melting of the seals of the rotating plugs is initiated.

2. The instrumentation connectors and pressure-transducer lines are disconnected from the terminal box of the instrumented subassembly, and the blind cover plate is installed over the connector receptacles.

3. At the instrumented-subassembly mechanism, the lower interlock yoke is manually disengaged by pulling up the locking pin, sliding the yoke back, and reinserting the pin to hold the yoke back. Indicating lights at the fuel-handling console reflect this action.

4. From the vertical panel of the fuel-handling console, the instrumented subassembly is raised by momentarily pressing the "elevator up" pushbutton. The subassembly continues to run to its up position, where it stops. The lights in the pushbutton indicate this action.

NOTES: a. The instrumented subassembly is raised first so that the subsequent down motion of the control-rod-drive lifting platform does not bring the bottom of the subassembly into possible contact with the bottom grid pins.

b. The upper interlock yoke is not engaged at this time. This allows the subassembly to float on its spring support and thereby be able to move in case there is binding between it and the reactor-vessel cover in later operations.

5. Pressing the next pushbutton in sequence A causes the following action: The platform is raised about 1/8 in. to clear the platform blocks.

The blocks are retracted to allow downward motion of the platform. The platform is lowered about 1 in. to its "down" elevation. The control rods are now supported by the bottom grid pins.

6. Continuing with the sequence-A pushbuttons opens the control-rod gripper jaws. Simultaneously, the platform locks are opened; they are geared to jaw drives 3 and 9.

7. In the next step, the platform is raised 4 in., to its "up" elevation. The control rods are left behind in their down position. The control-rod gripper jaws are now clear of the tops of the control rods.

8. The control-rod gripper jaws are closed and opened to check that the control rods have been left down.

9. The packing glands on the reactor-vessel-cover lifting columns are opened. The cover is unlocked and raised about 9 ft.

10. Since no further relative motion occurs between the instrumented subassembly and any other mechanism, the upper interlock yoke is engaged to lock the subassembly in its up position by pressing the "upper yoke engage" pushbutton.

11. The cover-column packing glands are closed.

12. The electrical cables that provide the connections for most of the functions of the control-rod drives, the platform, and the cover are manually disconnected to allow free rotation of the plugs. This step includes disconnecting the two main cables of the instrumented-subassembly drive from junction box JB-4.

A few more steps involving moving the safety rods and the gripper and holddown mechanisms complete the preparations of sequence A. Then, unrestricted fuel handling involving sequences B, C, D, E, F, and G begin. In these operations, fuel subassemblies are transferred between the storage basket and the reactor core.

After the required unrestricted fuel handling has been completed, the reactor components are brought into position for reactor operation by the operations of sequence H at the fuel-handling console, as follows:

1. The rotating plugs and other components are brought to their "reactor operate" positions.

2. The electrical cables for the control-rod drives, the platform, and the cover are connected. The two cables for the instrumented-subassembly drive are connected to JB-4.

3. The upper interlock yoke of the instrumented subassembly is released by pressing the "upper yoke retract" pushbutton. This action allows the subassembly to float during subsequent operations.

4. The cover packing glands are opened, and the cover is lowered to its "down" position. The cover and other packing glands are closed, and the cover locks are engaged.

5. The platform blocks are retracted, and the platform is lowered to its "down" elevation. The tops of the upper adapters of the control rods are now within the jaw assemblies.

6. The control-rod gripper jaws are closed. The platform locks are driven into place when jaws 3 and 9 close.

7. The platform is raised to an elevation slightly above the tops of the blocks.

8. The platform blocks are driven into place.

9. The platform is lowered onto the blocks.

10. The instrumented subassembly is lowered to its down position by pressing the "elevator down" pushbutton.

11. The lower interlock yoke is engaged manually to lock the instrumented subassembly in its down position.

12. The blind cover plate on the terminal box is removed, and the instrumentation connectors and pressure-transducer lines are reconnected. All components are now at their reactor operating positions.

13. If all the required interlocks are satisfied, a reset button at the end of sequence H can be actuated to provide a necessary interlock for reactor operation.

APPENDIX K

Sensor Readings from Subassembly XX01

The ten graphs (Figs. 44-53) in this appendix depict the readings of selected sensors throughout the irradiation of the subassembly. These are derived from records of the strip-chart recorders and the MIDAS.

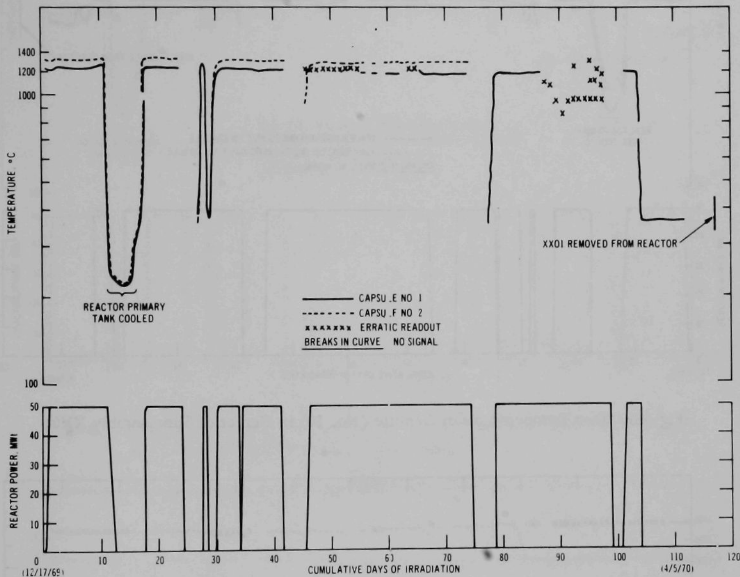


Fig. 44. Fuel-centerline Temperatures in Two Adjacent Capsules in Row Closest to Core Center in Subassembly XX01

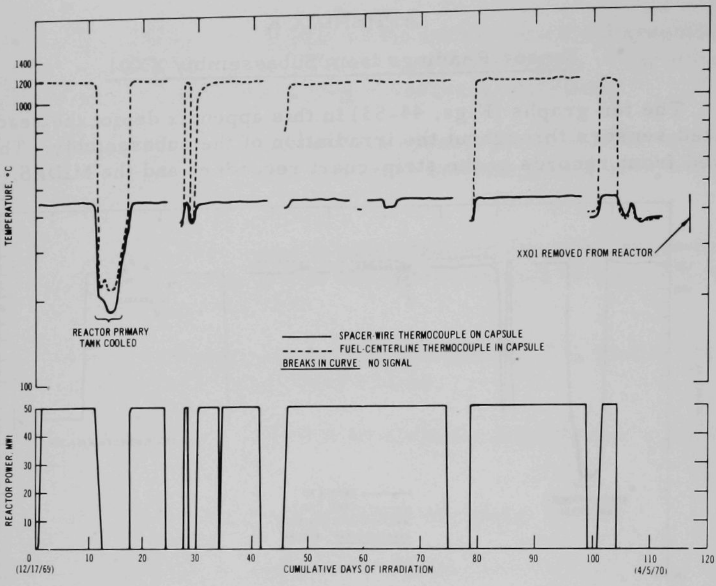


Fig. 45. Two Temperatures of Capsule (No. 10) in Center of Subassembly XX01

Fig. 46. Two Temperatures of Capsule (No. 3) Closest to Core Center in Subassembly XX01

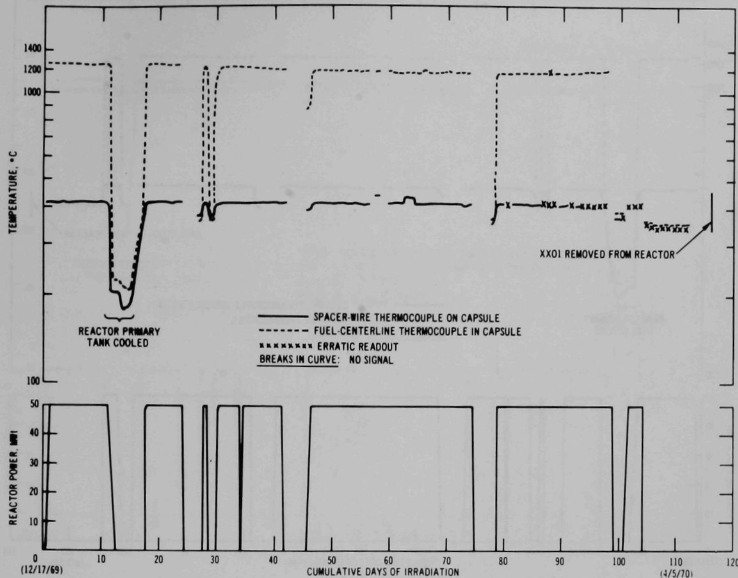


Fig. 47. Two Temperatures of Capsule (No. 7) at Periphery of Subassembly XX01 and in Second Row Closest to Core Center

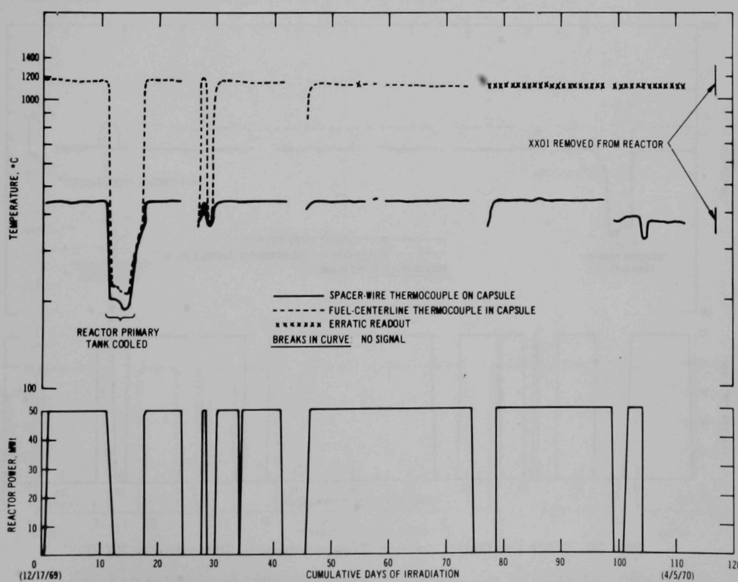


Fig. 48. Two Temperatures on Capsule (No. 17) Farthest from Core Center in Subassembly XX01

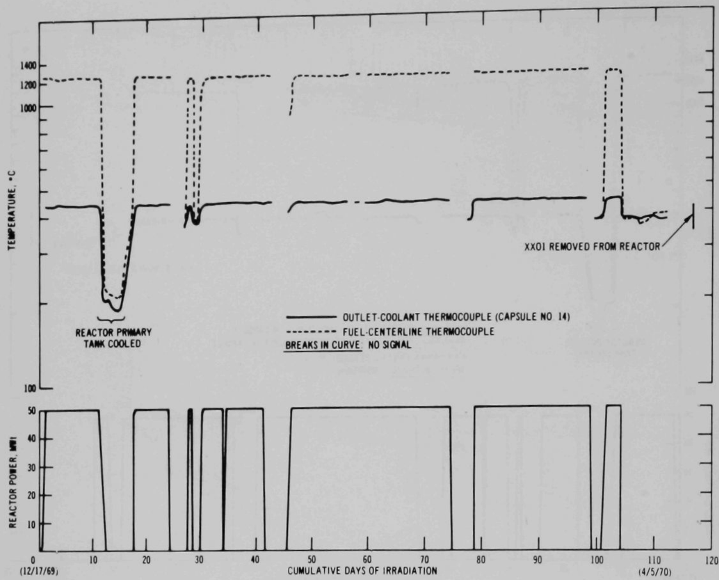


Fig. 49. Fuel-centerline Temperature in Capsule No. 15 and Adjacent Outlet Coolant Temperature in Subassembly XX01

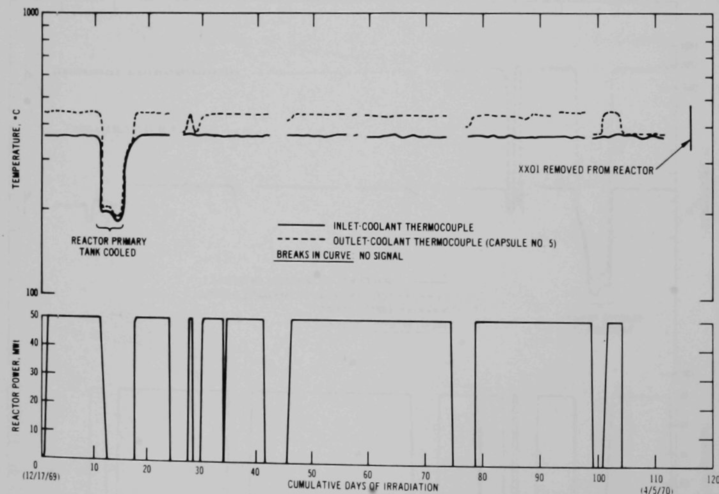


Fig. 50. Inlet and Outlet Sodium Temperatures in Subassembly XX01

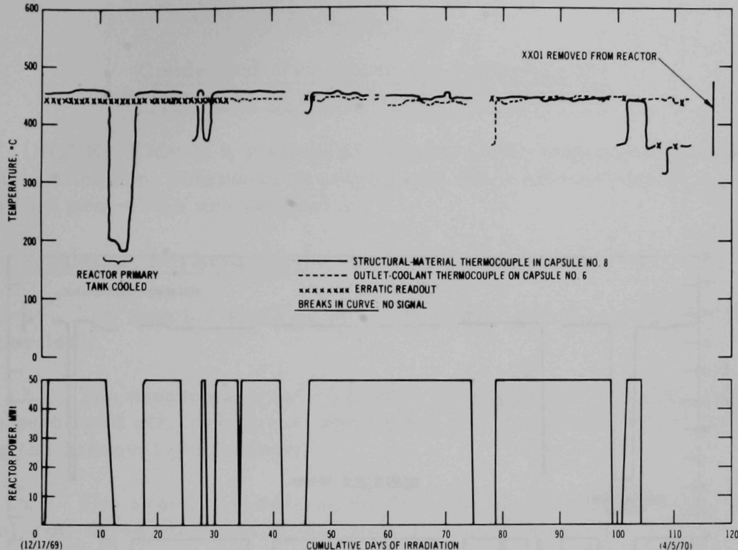


Fig. 51. Structural-material Temperature and Outlet Coolant Temperature in Subassembly XX01

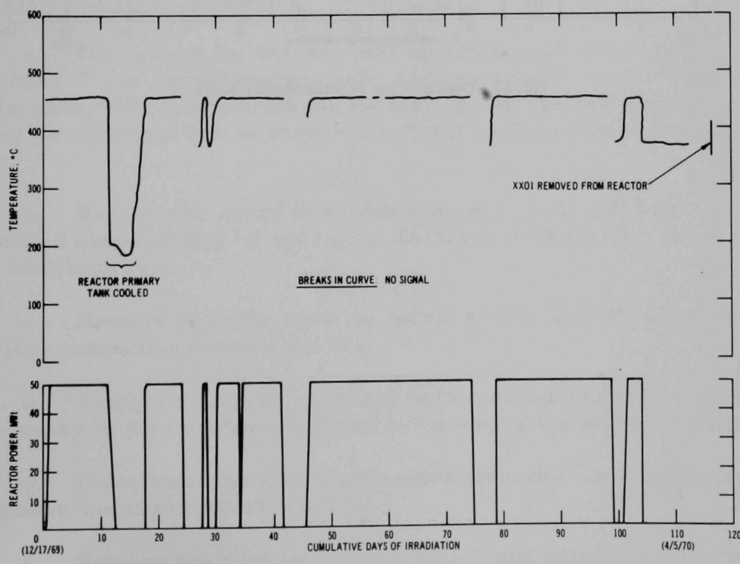


Fig. 52. Temperatures in Structural-material Capsule No. 19 in Subassembly XX01

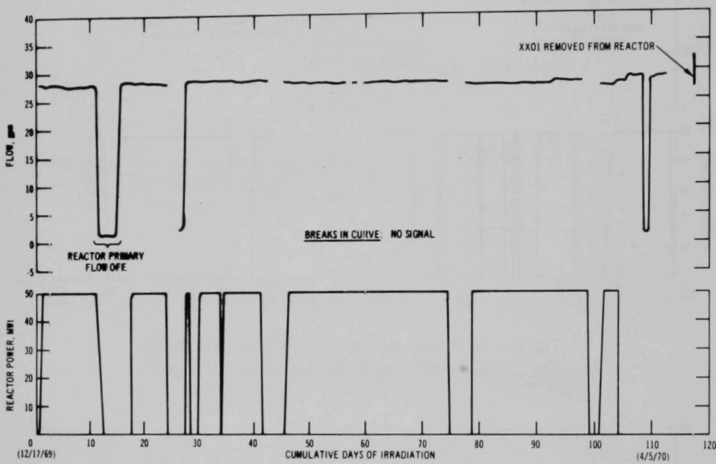


Fig. 53. Coolant Flow in Subassembly XX01

APPENDIX L

Condensed Procedure for Removing the Instrumented Subassembly from EBR-II

(NOTE: This is a condensed version of the authorized procedure. For simplification, reference drawings and other information in the authorized procedure are omitted.)

1. Prerequisites for Removal

a. The reactor shall be shut down, with primary-tank sodium at 580°F or less.

b. The electrical cutoff switches of the primary-sodium pumps are to be turned off, locked out, and tagged so the pumps cannot be operated during the removal procedures.

c. The reactor-vessel cover is to be "down" and "locked," and the control-rod-drive platform in the "operate" position.

d. The fuel-handling console is to be energized and in pushbutton sequence-A mode (in which mode the reactor is prepared for fuel handling).

2. Disassembly of Elevator and Terminal Box

a. Disconnect the in-core instrument connectors in front of terminal box. Close the instrument-tube valves on top of the terminal box, and disconnect the tubing from the valves. Install the blind cover on the front of the terminal box to actuate the "cable disconnected" interlock switch.

b. Retract the lower interlock yoke manually, and raise the instrumented subassembly by operating the drive mechanism. Engage the upper interlock yoke.

c. Remove the side cover of terminal box, and cut all tubing and electrical connections inside the box.

d. Retract the upper interlock yoke, and lower the instrumented subassembly to its full-down position by operating the drive mechanism.

e. Disconnect the electrical cables from the lower interlock yoke, and remove the lower interlock yoke.

f. Remove the push-pull force switch and potentiometer assembly.

g. A space of approximately $1\frac{1}{8}$ in. remains between the bottom surface of bellows-seal flange and the top surface of the bellows support structure. Lower the instrumented subassembly until these two surfaces are close together by manually turning the elevator support nut counterclockwise until the subassembly rests on the adapter of the control-rod guide thimble. The load-transducer readout should go to zero when the subassembly is supported by the guide thimble. There should be about 0.125 in. of clearance between the bottom surface of the bellows-seal flange and the top surface of the upper plate of the bellows support structure. In this position, the bellows-seal flange is anchored to the upper plate by two shoulder screws which restrain the bellows top flange from rotation and limit vertical movement.

h. Disconnect the electrical cables of the drive mechanism from the junction box located on top of the terminal box.

i. Remove the reactor-cover drive motor and the two horizontal support channels of the reactor-cover support structure.

j. Remove the connecting pin supporting the subassembly, and remove the elevator-assembly components.

k. Remove the bolts securing the terminal-box flange to bellows-seal flange, and remove the terminal box.

3. Removal of Connecting Assembly

a. Loosen the shoulder screws installed previously in step 2.g, and insert a 1/8-in.-thick filler plate between the bellows-seal flange and the extension-tube flange.

b. Remove the seal nut at the top of the instrumented-subassembly extension tube, the spring-support screws, the coupling-support-flange washer and spring, the extension-tube clamp nut, and the extension-tube support flange.

c. Remove the drywell-liner flange.

d. Lift the release rod a small distance, remove the release-rod snap ring, and attach the release-rod extension tool.

e. Attach the coupling-lifting tool to the coupling sleeve. Lift the release rod and the extension tool slightly, and retain the rod by inserting a pin into the hole in the extension tool.

f. Install the adapter valve on top of the bellows-seal flange, with the valve gates in the open position; then clamp the extension tube by turning the locking screw of the adapter valve.

g. Position the existing pulling-pipe assembly over the extension tube and 18 in. above the adapter valve, and attach its internal piston to the coupling-lifting tool.

h. Using a dynamometer to monitor the hoisting load, raise the coupling-lifting tool 24 in. The coupling sleeve is pulled initially $1\frac{1}{2}$ in. to release the coupling jaws. Continued pulling causes the sleeve and the coupling to move together and to disengage the coupling at the top end fixture of the subassembly. Normal force for decoupling, indicated on the dynamometer, is of the order of 100-150 lb. If the coupling jaws remain closed, this would be indicated by excessive force on the dynamometer, in which case the release rod may be lowered to open the jaws.

i. Place the pulling pipe on top of the adapter valve. Hoist the coupling assembly completely into the pulling pipe after pausing for dripping and cooling of the assembly. Then, close the top gate of the adapter valve and the pulling-pipe valve.

j. Raise the pulling pipe, containing the coupling assembly, out of the adapter valve, and transfer the pulling pipe to a reactor-building storage pit.

k. Remove the coupling assembly from the pulling pipe.

4. Lead Cutting and Removal of Extension Tube

a. Install the cutting-tool guide sleeve on top of the adapter valve.

b. Attach the cutting tool to the hoisting device.

c. Position the cutting tool directly over the extension tube, and line up the V-groove above one of the cutting blades of the tool with the V-groove on the cutting-tool guide sleeve. The guide key on top of the cutting tool then points radially outward from the reactor centerline.

d. Insert the cutting tool through the adapter valve until the top of the tool is 16 ft from the top of the adapter valve. Hold the cutting tool in this position for 50 min, to allow warm-up of the cold cutting tool to avoid solidification of sodium within the extension tube. During insertion, the radial orientation of the cutting tool is maintained by the drywell liner, except for the last 9 in., when the orientation is maintained by the cutting-tool guide sleeve and key. When the cutting tool is fully inserted, marks on the sensing rod and cutting tool should line up.

e. Remove the hoisting device and eye bolt. Then remove the cutting-tool guide sleeve from the top of the adapter valve and the cutting-tool guide key from the top of the cutting tool.

f. Attach the cutting-tool adapter to the screw threads of the extension tube.

g. Attach the cutting-tool drive system to the bellows support structure, connect the associated readout equipment, and perform the lead-cutting operation.

h. Disconnect the readout equipment, and remove the cutting-tool drive system from the bellows support structure.

i. Unclamp the extension tube by loosening the locking screw of the adapter valve.

j. Attach the extension-tube lifting tool to the cutting-tool adapter. Line up the slot in the lifting tool with the slot in the cutting-tool shaft.

k. Position the existing pulling-pipe assembly over the extension tube and 18 in. above adapter valve, and attach its internal piston to the extension-tube lifting tool.

l. Using a dynamometer to monitor the hoisting load, raise the cutting-tool assembly and extension tube together. The sensing rod should remain at its initial elevation during the first 5 in. of upward travel of the extension tube. If the sensing rod does not remain at its initial elevation (i.e., moves upward), the extension tube and the subassembly are not separating. In that case, lower the subassembly, remove the lifting tool, and screw a cutting-tool-assembly lifter into the cutting-tool assembly, thus separating the subassembly from the extension tube. Upon separating, raise the cutting tool and extension tube 24 in. Then, lower the pulling pipe to the adapter valve.

m. After pausing for dripping and cooling, hoise the cutting tool and extension tube together completely into the pulling pipe. Then, close the top gate of adapter valve and the pulling-pipe valve.

n. Raise the pulling pipe, containing the cutting tool and extension tube, out of the adapter valve, and transfer the pulling pipe to a reactor-building storage pit.

o. Remove the extension tube and cutting tool from the pulling pipe.

p. Remove the cutting tool from the extension tube.

q. Remove the adapter valve from the bellows-seal flange, and install a blind flange at this location.

r. Install jumpers in the fuel-handling console to permit fuel handling while the instrumented-subassembly drive system is disconnected.

s. Remove the subassembly from the reactor, and place it in the storage basket.

ACKNOWLEDGMENTS

The design, development, fabrication, and operation of the EBR-II instrumented-subassembly system drew upon the talents and time of so many people that any attempted listing of all who made significant contributions would probably contain serious omissions. We express sincere gratitude to all who contributed their ability and dedication toward the successful completion of the task.

Special thanks are extended to E. Hutter (EBR-II) and T. P. Mulcahey (ETD) for continuous guidance and critical reviews of designs during the entire task.

REFERENCES

1. L. J. Koch *et al.*, *Hazard Summary Report: Experimental Breeder Reactor II (EBR-II)*, ANL-5719 (May 1957) and ANL-5719 Addendum (June 1962).

2. A. Smaardyk, C. J. Divona, R. H. Olp, and E. Hutter, *Design and Analysis of Instrumented Subassembly System for EBR-II*, ANL-7423 (June 1968).

3. N. J. Carson, N. R. Grant, N. F. Hessler, H. F. Jelinek, R. H. Olp, and A. B. Shuck, *Fabrication of EBR-II, Core I Fuel Elements*, ANL-6276 (Dec 1962).

4. *Reactor Development Program Progress Report: March 1967*, ANL-7317, pp. 13-15 (Apr 28, 1967).

5. J. R. Folkrod, *Design and Tests of Null-balanced Fission Gas Pressure Transducer and Controller*, Nuclear Applications and Technology *8*(5), 432-436 (May 1970).

6. J. W. Hilborn, *Self-powered Neutron Detectors for Reactor Flux Monitoring*, Nucleonics *22*(2), pp. 69-74 (Feb 1964).

7. *Reactor Development Program Progress Report: August 1968*, ANL-7487, p. 51 (Sept 26, 1968).

8. *Reactor Development Program Progress Report: March 1968*, ANL-7438, p. 29 (Apr 26, 1968).

9. G. F. Popper and A. E. Knox, *FARET In-Core Instrument Development*, ANL-7161, pp. 33-38 (July 1966).

10. D. E. Walker, P. J. Halfman, and J. H. Sanecki, "Xenon Tagging of Instrumented Fuel Capsules for Use in EBR-II," *National Symposium on Developments in Irradiation Testing Technology*, CONF-690910, pp. 59-70 (1969).

REFERENCES

1. [illegible] ANL-7[illegible] ([illegible]).

2. A. [illegible] [illegible] ANL-7[illegible] ([illegible] 1968).

3. N. J. Carson, W. R. [illegible], R. R. [illegible], H. E. [illegible] [illegible] ANL-6216 ([illegible]).

4. "Reactor Development Program Progress Report: March 1967," ANL-7317, pp. 14-19 (Apr 28, 1967).

5. J. R. [illegible], Design and Tests of Self-balanced Reactor [illegible] [illegible], Nuclear Applications and Technology (5), 432-438 (May 1968).

6. J. W. Hilborn, "Self-powered Neutron Detectors for Reactor Flux Monitoring," Nucleonics 22(2), pp. 69-74 (Feb 1964).

7. "Reactor Development Program Progress Report: August 1968," ANL-[illegible], p. 51 (Sept 26, 1968).

8. "Reactor Development Program Progress Report: March 1968," ANL-[illegible], p. 125 (Apr 26, 1968).

9. G. R. [illegible] and R. W. Knox, "EBR-II [illegible]," ANL-7[illegible], pp. [illegible] (July 1968).

10. D. E. Walker, [illegible], and J. H. [illegible], "Boron Tagging of Instrumented Fuel Subassemblies for Use in EBR-II," National Conference on Development in Irradiation Testing Technology, CONF-690910, pp. 59-70 (1969).